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Operation REDWING Interim Test Report Program 2 110837

FALLOUT STUDIES

IN

OPERATION REDWING

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ABSTRACT

Program 2 had the Department of Defense responsibility for the proper prosecution of the Nuclear Radiation and Effects Program in Operation REDWING. This report covers the portion of the program concerned with the distribution of radioactivity in the cloud resulting from nuclear explosions and the subsequent fallout of material from the cloud.

Participation involved the following agencies: Evans Signal Laboratory; Naval Radiological Defense Laboratory; Scripps Institution of Oceanography; New York Operations Office, AEC; Chemical and Radiological Laboratories, ACC; and Air Force Special Weapons Center. REDWING large yield events having primary participation were Cherokee, Zuni, Flathead, Navajo, and Tewa with secondary measurements made on events LaCrosse and Mohawk.

A wide variety of instrumentation was employed by the various laboratory groups. Rockets and manned aircraft made penetrations into the cloud and stem. Instruments recorded the time of arrival of fallout, collected incremental and gross samples of fallout, and measured the radioactivity in the air, on land surfaces, and in the lagoon and ocean waters. Samples were collected by a number of different means, including manned ships in the downwind fallout area; skiffs deep moored in the open ocean; barge, raft, and land stations in the Bikini Lagoon. Aircraft and ships were used to survey the open ocean areas, helicopters with detectors suspended below and monitor teams surveyed the land areas. The water in the lagoon was examined.

Data consisted of time and rate of arrival of radioactivity; character of fallout material including particle size, composition, and activity, total exposure on land; and exposure rates on land, in the air, and in the lagoon and ocean water. Wind data and the size and shape of the visible cloud and stem were recorded to assist with the analysis of the fallout pattern.

No fallout was measured from the Cherokee air burst. Preliminary results show a difference in the nature of fallout material between water surface (Flathead and Navajo) and land surface (Zuni and Tewa) bursts. The former consisted of an aerosol, mud, and a salty slurry and the latter of a fine dry solid material resembling modified coral. High exposure rates were measured in the lower layer of the cloud and little activity was detected in the stem although large active particles were collected which apparently came from lower stem altitudes. Particle fall, time of arrival, and exposure plots have been developed from the data. EXPOSURE AND RATE CONTOURS ARE FROM PRELIMINARY DATA AND MUST BE USED WITH CAUTION. Some in-close readings are given and those near the Mohawk crater extrapolated to H/1 hour in many cases exceeded 10,000 r/hr. These values are higher than any previous extrapolated data based on D-day measurements.

It is tentatively concluded for the size of shots involved that radioactive fallout material originates in the lower layer of the nuclear cloud and that there is relatively little activity in the stem.

A minimal air burst over water does not produce fallout of military significance.

The exposure rate from surface burst fallout is probably proportional to the radiological yield.

Tentatively and within the definitions of this report a [redacted] yield) surface burst will produce an area of over 1,500 square miles ~~contaminated~~ to a level which will be lethal to exposed personnel. The sickness area will comprise more than 3,500 square miles.

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FOREWORD

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PREFACE

This report is a summary and consolidation of the preliminary information available on the fallout studies at Operation REDWING. Data is presented from many of the projects in Program 2 which worked individually and in close cooperation to document the fallout. Appendix A gives some information on the individual projects and the type of data each obtained. A number of projects also gathered data on other problems such as initial radiation and contamination and decontamination. The preliminary results of these efforts are not included in this report since they will be presented in detail in the individual project reports and are also covered in the Task Unit 3 Summary Report.

Since this report was written within a few weeks after the conclusion of Operation REDWING, the data is necessarily preliminary and subject to possible major changes. Much of the data from detailed laboratory analysis of the fallout samples and from careful interpretation of the records was not available. However, it was felt that the general fallout picture, including the estimated radiation contours for the individual events, was of sufficient immediate interest to warrant presentation of the results although they were subject to change.

This consolidation would not have been possible without the cooperation and assistance of the following Project Officers and their projects:

Mr. Peter Brown, Projects 2.1 - 2.2, Evans Signal Laboratory;

Mr. Richard R. Soule, Project 2.61, Naval Radiological Defense Laboratory;

Mr. Feenan D. Jennings, Project 2.62, Scripps Institution of Oceanography;

Dr. Terry Triffet, Project 2.63, Naval Radiological Defense Laboratory;

Mr. Robert T. Graveson, Project 2.64, New York Operations Office, AEC;

Mr. Manfred Morgenthau, Project 2.65, Army Chemical Center;

Colonel Ernest A. Pinson, USAF, Project 2.66, Air Force Special Weapons Center;

Mr. Heinz Rinnert, Project 2.71, Naval Radiological Defense Laboratory; and

Mr. Michael M. Bigger, Project 2.10, Naval Radiological Defense Laboratory.

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CHAPTER 1

INTRODUCTION

The material in this report is organized around the three basic types of shots in Operation REDWING in which fallout was documented: land surface, air, and water surface bursts. The land surface bursts will be discussed in detail, and where possible, the other types of shots will be discussed by comparison with the land surface burst phenomena.

1.1 LAND SURFACE BURSTS

1.1.1 Definition. A land surface burst is defined as the explosion of an atomic weapon at the surface of land or at a height above the surface less than the fireball radius at the time of break-away of the shock front. Based on the test results from atomic weapons to date, the fallout contamination can be of primary importance for such a burst, extending the area in which personnel casualties are inflicted far beyond the regions of blast and thermal effects, and denying access to some areas for a long post-shot period.

1.1.2 Previous Test Results. Only four land surface shots, as shown in Table 1.1, have been documented for fallout to any appreciable extent. These were the surface ("S") shot in Operation JANGLE, the MIKE shot in Operation IVY, and the BRAVO and KOON shots in Operation CASTLE.

1.1.2.1 JANGLE Surface Shot. On the JANGLE surface shot the distribution of bomb debris was documented in detail, particularly close in. The low yield of [redacted] made it possible to survey the radiation pattern directly with hand and vehicle carried survey instruments.

TABLE 1.1 Summary of Data on Previous Land Surface Shots

Shot	Yield	Date and Location	Remarks	References
JANGLE Surface		19 Nov 51. Yucca Flat, Nevada Test Site.	Fallout was well documented, particularly close in.	1 thru 16
IVY MIKE (Shot 1)	DELETED	1 Nov 52. FLORA, Eniwetok Atoll.	Fallout was documented in the upwind and crosswind directions.	10, 11, 17, 18, 19
CASTLE BRAVO (Shot 1)		1 Mar 54. West of CHARLIE on reef, Bikini Atoll.	Close in fallout was well documented considering damage to instrumentation. Some late survey data was obtained about 150 miles downwind.	10, 11, 20 thru 27
CASTLE KOON (Shot 3)		27 Mar 54. West end of TARE, Bikini Atoll.	Fallout instrumentation limited. Documented about 15 miles downwind.	10, 11, 20 thru 27

Measurements of the quantity of fallout material, time of arrival, and rate of arrival were obtained. Fairly complete radiochemical and radiophysical analyses of the fallout particulate were made. The 100 r/hr contour at 1 hour after detonation extended more than 4,000 yards downwind and had a crosswind extent of 500 yards. The downwind distance extended well beyond the region of blast and thermal damage and therefore the JANGLE results showed appreciable areas with fallout of military significance. Considerable fractionation was observed in the fallout from the JANGLE shot and a dependence of the radiochemical composition upon particle size was indicated. The distribution of activity with particle size and the distribution of activity on and within particles was studied in detail. It was found that almost all the activity was associated with particles larger than 100 microns in diameter. Results also showed that activity was distributed uniformly in some particles while in other particles this was not true. The activity was almost never found to be concentrated near the outside of the particle. Active particles ranged from being colorless to jet black, but the activity was usually associated with the darker colors.

1.1.2.2 The IVY MIKE Shot. The IVY MIKE shot of about [redacted] was documented only in the upwind and crosswind directions. Measurements of the crosswind fallout arrival times were independent of distance from ground zero and the duration of the observed fallout was approximately 1 to 2 hours. No evidence of any particle size fractionation with crosswind distance was found and there were only meager indications of particle size fractionation with time.

1.1.2.3 CASTLE BRAVO Shot. Shot 1 in Operation CASTLE was a land surface burst with a yield of [redacted]. This shot produced fallout at levels of military significance over a tremendous area. Results of this shot showed that weapons of this type and yield can be expected to produce levels of residual radiation hazardous to human life over several thousand square miles. The threshold value for radiation levels of military significance is indeed difficult to specify quantitatively since it varies widely, depending upon the particular effect under consideration. However, in this report, radiation levels above 5 r/hr at 1 hour after detonation are arbitrarily considered to have military significance. (Reference 28.) Gamma levels of military significance were found to exist at a downwind distance of at least 280 nautical miles. It was concluded that an area upwards of 20 miles in width and 120 miles in length downwind would produce casualty effects in the case of this type of surface land detonation with a yield in the [redacted] range. The data showed a substantial contribution to the residual activity from neutron capture products of U^{238} including U^{237}, U^{239} and its daughter Np^{239}, and Np^{240}. This contribution influenced markedly the gamma energy distribution and decay rate. Theoretical considerations indicate that the relative contribution from the Np^{239} builds up to a maximum four days after the shot and its effect is to reduce the gross decay rate below that of the fission products alone.

1.1.2.4 CASTLE KOON Shot. The KOON shot at CASTLE had a yield considerably less than the BRAVO shot. Because of previous damage to the instrumentation and operational difficulties, fallout documentation for for this shot was limited to total collection type instrumentation.

1.1.3 Mechanism of Fallout. When a nuclear detonation occurs, the long lived radioactive products formed are of three types:

a. Fission products.

b. Neutron capture products formed in the reacting bomb materials.

c. Neutron capture products formed in the neighborhood, such as the inert bomb materials, enclosing building, and the nearby land or water.

In pure fission weapons the first of these types predominates over the others. When an appreciable part of the fission yield results from secondary fission of U^{238}, the neutron capture products, particularly Np^{239}, contribute significantly to the activity during the subsequent days. In any case, the activity induced in the local soil and other neighboring materials is completely masked whenever it is in the presence of fission products and activity from neutron capture products. When a weapon is detonated so that a portion of the fireball intersects the ground, an appreciable amount of ground material becomes incorporated in the fireball in the gaseous, liquid, and even solid state. This material becomes intimately mixed with the fission and activation products. As the fireball cools, this material condenses and a considerable fraction of the activity becomes associated with the material particles. The rapid upward movement of the fireball and ensuing cloud [1] probably carries this material upward and subsequently outward with the radial expansion of the cloud.

Once the turbulent motion in the cloud has abated, the particles commence to fall at a rate determined by their size and to move horizontally with the local air motion. Those particles with a diameter greater than 75 microns will fall to the surface within a day and

1/ For the purpose of this report the cloud is defined as the upper part of the nuclear mushroom. The mushroom therefore consists of the cloud and stem.

contribute to the local fallout contours. Smaller particles take longer times to settle and are also influenced appreciably by vertical air motions. Air turbulence and various weather disturbances result in a pertubation of the fallout pattern.

The problem of detailed fallout prediction then naturally separates itself into two parts. The first is the establishment of an appropriate model for the initial ~~cloud~~ mushroom, including the distribution of activity as a function of particle size and position at a time when the turbulent motions no longer affect the particles, that is, when they are moved only by gravity and the prevailing wind. This initial distribution is expected to be a function of the total yield and fission yield of the weapon and its environment, and also to be affected somewhat by the meteorological conditions, particularly the location of the tropopause. In addition, there are a number of other considerations such as peculiar condensation and falling effects, i.e., change in particle size with time, which play a role in any detailed model.

The second part of the analysis involves the prediction of the time of arrival and location on the surface associated with each position and particle size in the ~~cloud~~ mushroom and hence the construction of intensity contours. This procedure involves the complete wind structure in the area of fallout from shot time until the time all the fallout of interest has reached the surface. Such a complete analysis as is outlined above involves the use of detailed weather data and would, in general, be very time consuming. For tactical military situations and civil defense applications, the accuracy desired does not demand such a complete analysis but the answers are desired in a short time. Therefore, it is convenient to describe the fallout pattern in terms of a few parameters such as area, downwind distance, crosswind distance, size of circle around ground zero, etc.

The scaling relations for these parameters can then be established in terms of weapon and environmental characteristics and a gross estimate of the meteorological conditions.

Experiments on fallout scaling models have been conducted with high explosive charges ranging from 150 pounds to 50 tons exploded on a land surface. The JANGLE surface shot yielded data at 1.2 KT and the IVY MIKE and CASTLE BRAVO data represent points at 10-15 MT, a yield factor of 10^4 higher than JANGLE. The large yield data that was obtained was particularly sparse in both the downwind and crosswind directions.

The simplest scaling law that has been proposed involves scaling all contour dimensions, as well as the contour values, by the cube root of the yield. This procedure conserves the total material in the weapon and implies the same fraction of all size weapons to be locally deposited. The limited measurements performed for CASTLE BRAVO, however, indicate contour dimensions appreciably larger than the values scaled from the JANGLE surface shot and therefore a procedure of scaling by interpolation between measured values is probably much more reliable. Curves have been developed which are based on all the available data and are most practical for rapid rough estimates (Reference 29).

Obviously, insufficient fallout test data has existed to perform reliable scaling. The most profitable plan of attack on this problem is probably to first develop a detailed model and then infer the scaling laws from it. In this way the effect of other parameters such as wind speed and shear can be better evaluated. Therefore, the primary goal of the fallout documentation at Operation REDWING was to analyze the fallout in every detail as completely as possible and thereby to contribute to the development of a detailed model.

1.1.4 Objectives. The general objective of the Fallout Program in Operation REDWING was the complete fallout documentation of shots CHEROKEE, ZUNI, FLATHEAD, NAVAJO, and TEWA with some incidental participation on other shots of generally smaller yield. The following were the specific objectives in documenting the fallout:

1.1.4.1 Collection of the Fallout Material. This objective includes the collection of the fallout material at the following stations:

1. Islands of Bikini Atoll.
2. Floating collection platforms located in the Bikini Lagoon and ocean fallout area.
3. In the ocean water.
4. At a remote atoll location (Rongerik).

1.1.4.2 Radiation Readings Over Land Type Surfaces. One objective was to gather radiation readings at the above mentioned locations which could be reduced to yield the contours that would have existed if the fallout had occured over an equivalent land area.

1.1.4.3 Distribution of Activity in the Ocean Areas. This objective was to make use of the ocean as a collector of activity and to evaluate a method of inferring land surface radiation contours from radiation measurements in and above the ocean.

1.1.4.4 Distribution of Activity in the Nuclear Cloud. This objective was to obtain data on the initial distribution of activity in the stabilized cloud and to test a method of obtaining such data with rocket borne detector-telemeter units. The intent was to obtain data to compare the relative activity of the cloud and stem and the distribution of activity within each of these regions. In addition, it was expected that some additional data on the distribution of activity in the cloud and the exposure rates to personnel would be obtained from manned aircraft flights into the cloud at times of 1/2 to 1 hour after detonation.

1.1.4.5 Analyses of the Collected Fallout Material. Various physical and chemical analyses on the fallout material were planned to give the following information:

1. Particle size distribution as a function of time of collection and location.
2. Gross decay of the fallout activity (starting at very early times).
3. Distribution of activity on and within particles and as a function of particle size.
4. Quantity of certain individual nuclides and fractionation.

1.2 AIR BURSTS

1.2.1 Definition. The air burst of an atomic weapon is defined as one in the air above land or water at a height greater than the radius of the fireball.

1.2.2 Previous Test Results. A number of tests of weapons of relatively small yields in Nevada have given results which show that the

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fallout of radioactive material from an air burst is essentially negligible from a military standpoint. These tests were performed with air drops and bombs detonated on towers at such heights that the fireball did not reach the surface of the earth. The largest yield air burst prior to Operation REDWING was the IVY KING shot which was detonated at an altitude of 1,500 feet on 16 November 1952, over the ocean north of YVONNE at Eniwetok Atoll. The yield was approximately [redacted] Some very rough measurements on islands in Eniwetok Atoll indicated that the fallout activities were so small that at times as early as 6 hours after KING shot, the observed ~~intensities~~ exposure rates at all islands except YVONNE ~~were consistent with~~ could be attributed to the 15 day old fallout from MIKE shot. On YVONNE, within 4,000 feet of the ~~birst~~ burst point, the ~~intensity~~ exposure rate (of the order of 25 R/hr at H+1 hr) was only about 2 per cent of the activity produced at 18,000 feet from ground zero at comparable times after each shot. It was therefore concluded that there is little external radiation hazard from fallout due to an air burst at a scaled height as high as that of KING shot. BEST AVAILABLE COPY

<u>1.2.3 Mechanism of Contamination</u>. Previous weapons tests have consistently shown that air bursts, whether air drop or tower shots, produce little fallout contamination as compared to the same yield land surface burst. The conclusion from such data is that the hot fission products do not have an opportunity to condense onto the ground particulate matter picked up by the cloud. However, observations of air bursts of kiloton weapons have shown that a thin stem consisting of ground material is sucked up into the center of the rising fireball. There are two possible explanations as to why the radioactive material

does not deposit on this material: (1) by the time the ground material arrives, the fireball may have cooled sufficiently so that the fission products have solidified and are no longer available for deposition on other matter. (2) The internal motion of the fireball may be such that the ground material and the fission products do not come in contact. For example, the observed toroidal motion might consist of the bomb products in a narrow internal ring with the ground material flowing over the surface.

If either of these reasons explains the lack of contamination for previously observed air bursts, there is no guarantee that they will also hold for multimegaton bursts. The fireball remains hot for a longer period of time and the internal motion could differ in character between widely different yields. Therefore, in view of the great tactical importance of a low air burst in offensive military operations, the documentation of fallout from a weapon in the megaton range detonated at a height slightly greater than the fireball radius was essential.

1.2.4 Objectives. The broad objective was simply to establish whether or not there was radioactive fallout of military significance from a megaton weapon detonated at minimal air burst conditions over a land surface. This objective could be accomplished by simply documenting the fallout completely in accordance with the detailed objectives for the surface land shot.

1.3 WATER SURFACE BURSTS

1.3.1 Definition. A water surface burst is defined as one exploded at the surface of water or at a height above the surface less than the fireball radius.

[redacted]

<u>1.3.2 The Role and Military Significance of Barge Shots</u>. The firing of a nuclear weapon mounted on a barge is truly a water surface shot because it is detonated within a few feet from the surface. The use of barges in firing nuclear weapons was introduced at Operation CASTLE where four of the six shots were located on barges. Table 1.2 presents the summary data on these shots. The use of this technique has been adopted principally for operational reasons; namely, the shot site can be prepared easily for the next event and the device is very portable in case of a change in plans. As far as the fallout program is concerned, the barge shot has a direct significance in terms of the effects of a deep harbor burst and may give information applicable to the surface of the open ocean. In addition, the basic dynamics of the cloud development should not be modified too much by the presence of water and it can be expected that a more complete understanding of the fallout from a barge shot, coupled with particle information from a few land surface bursts, can improve the state of knowledge of the fallout from land surface detonations.

<u>1.3.3 Barge Shots at Operation CASTLE</u>. The first shot at CASTLE had a yield much greater than expected and this resulted in a serious curtailment of the fallout program on this operation. A large number of experimental failures and equipment losses resulted from blast and water wave action, delays in shot schedules, and operational difficulties associated with the sampling of fallout over extended ocean areas. Consequently, fallout documentation of the barge shots was quite limited. However, a considerable amount of data was obtained from analysis of the

TABLE 1.2 Summary of Data on Previous Water Surface Shots

Shot	Yield	Date and Location	Remarks	References
CASTLE ROMEO (Shot 2)	DELETED	27 Mar 54. Barge in CASTLE BRAVO crater on CHARLIE Reef, Bikini Atoll.	Good crosswind fallout data but limited in the downwind direction.	20 thru 27
CASTLE UNION (Shot 4)		26 Apr 54. Barge in Bikini Lagoon.	Fallout documentation fragmentary. Limited upwind and crosswind data.	20 thru 27
CASTLE YANKEE (Shot 5)		5 May 54. Barge in Bikini Lagoon.	Water survey and sampling techniques used. No Bikini Atoll fallout instrumentation due to loss and damage.	20 thru 27
CASTLE NECTAR (Shot 6)		14 May 54. Barge in IVY MIKE crater on FLORA, Eniwetok Atoll.	Extensive instrumentation in Lagoon and northern atoll islands. Limited fallout data. Generally low levels of activity except few samples near ground zero.	20 thru 27

water samples and fallout material. There were indications that much of the contamination was in the form of an aerosol and hence differed from the fallout from a land surface burst.

1.3.4 Objectives. Again, the objective of the Fallout Program was the complete documentation of fallout from the barge shots. This was done by implementing the same detailed objectives as those for the land surface burst. The intent was to learn just how the fallout varied with the different yield barge shots and specifically how it differed from the land surface burst and air burst fallout.

1.4 OTHER TYPES OF BURSTS

From the standpoint of weapons effects, and in accordance with definitions mentioned earlier, the explosion of an atomic weapon at the top of a tower may be either an air burst or a surface burst depending on whether or not the fireball comes in contact with the surface, although the air burst characteristics may be slightly modified by the presence of the tower. However, the Fallout Program did not document completely any tower shots in Operation REDWING. The only other types of shots that have not been considered thus far in this report are the underwater and underground bursts. Operation REDWING did not include any shots of those types and therefore no attempt has been made to discuss their fallout phenomenology.

1.5 EFFECT OF FRACTIONAL RADIOLOGICAL YIELD

Operation REDWING provided the first opportunity for testing weapons in which the [redacted] In this report the fractional radiological yield is defined as the ratio of the fission yield to the total yield. It is to be expected that the effect of this extra parameter, the fractional radiological yield, on the fallout would be as follows: The location of the contours as well as the weight of non-radioactive material deposited should be a function of the total yield, but the gamma dose rate associated with each contour should be scaled proportionally to the fractional radiological yield. The amount of fission product material deposited is obviously scaled by the fractional radiological yield. In general, the definition of the fractional radiological yield can be extended to describe induced activity in bomb materials or "salting agents." In the case of "salted" weapons, this quantity could then be greater than unity since extra activity might be added without contributing to the total yield of the weapon.

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1.6 SUMMARY OF PROGRAM OBJECTIVES

The overall objective of the Fallout Program was to document completely the fallout from the shots of interest. Complete collection of data on the numerous parameters was necessary to improve scaling laws, to better understand the mechanism of fallout, and hence improve present fallout models.

For the high yield minimal air burst CHEROKEE, in particular, the objective was to determine if there was any fallout of military significance.

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In the case of the ~~water~~ surface shots it was expected to establish in detail just how fallout from water surface bursts differs from that due to land surface bursts.

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CHAPTER 2

EXPERIMENTAL DESIGN

2.1 REQUIREMENTS FOR DATA

Based on the detailed objectives outlined in the previous chapter, the instrumentation for the fallout program was designed to ~~obtain~~ perform the following ~~data~~ functions:

a. Collection of Fallout Material

b. Obtain Radiation Readings Over Land Surfaces

c. Obtain Radiation Readings In and Above Ocean and Lagoon Water

d. Obtain Radiation Readings In the Nuclear ~~Cloud~~ mushroom.

2.2 INSTRUMENTATION

In some instances, more than one agency had equipment that performed the same function, e.g. the time incremental collection of fallout material. In such cases the detailed features of the equipment were different since the equipment was designed and built by different agencies. No attempt has been made in this report to give a detailed description of the individual pieces of equipment. For further information the reader is referred to the individual project reports. Instead, instrumentation will be discussed as general types and according to its function.

2.2.1 Collection of Fallout Material.

2.2.1.1 Total Collectors. Total or gross collectors were used to collect the fallout material throughout the duration of fallout. One total collector used by Project 2.65 at its distant collector station was simply a wooden tray four feet by four feet by 18 inches deep. A total collector used by Project 2.63 was a tray three feet square by two inches deep. A variation of this latter type utilized the same tray design but added a layer of fiber glass honeycomb and had a cover which was designed to open and close before and after fallout, respectively. This covering was provided to preserve the samples and prevent any modification by environmental conditions before and after collection. A third type of gross collector used by Project 2.65 was conical with an opening at the top two feet in diameter and narrowing to a circle about 5 inches in diameter at the bottom where there was a stainless steel filter. Below the filter there was a small hose leading to a polyethylene bottle. The cover of the collector was designed to open upon a timing signal and then close automatically eleven hours later. A similar type of total collector used by Project 2.63 consisted of a 7 inch diameter funnel with a one-half inch diameter tube and a two gallon bottle, all of polyethylene, with a fiber glass honeycomb layer in the mouth of the funnel. A final type of a total collector used by this project consisted of filter paper through which fallout air was sucked by a pump.

2.2.1.2 Incremental Collectors. The largest number of incremental type collectors used were located at the Project 2.65 land stations and consisted of a covered steel tub 40 inches in diameter and 24 inches high. Fitting into this tub was a circular disc with 22 triangular sampling trays, each 3 3/8 inches by 10 inches by 3/4 inch deep. By means of a driving and timing mechanism, one tray at a time was exposed to the open air through a hole, the size of the sampling tray in the top cover. A door covered the sampling hole before the initial and after the final sampling. An external timing signal started the mechanism and succeeding trays moved into position at set time intervals. Exposure durations of 1 minute, 5 minutes, and 30 minutes were used for various collectors. The Project 2.63 type of incremental collector used was essentially a rainfall sampler in which the collecting trays had been modified. These trays exposed sensitive collecting surfaces about 3 inches in diameter successively for equal time increments. The trays were placed in the exposure position by means of a pair of interconnected vertical elevators. Each tray was exposed at the top of the ascending elevator and after exposure was pushed horizontally across to the descending one. For land surface shots, a grease coated cellulose acetate disc was used as a collection surface and for water shots, the same surface ~~were~~ was interspersed with discs of chloride sensitive films.

An experimental high volume filter unit was also used by Project 2.63. This device was, in effect, an incremental air sampler. It was designed to obtain gross aerosol samples in significant quantities under conditions of low concentration. It consisted of a single blower and 8 filter heads oriented upward enclosing 3 inch diameter filter packs that were changed at specified time intervals.

Project 2.65 used a tape fallout monitor which was an intermittent type of collector employing adhesive tape for the sampling surface which was exposed for periods of one minute for the first hour and periods of one hour for the next 47 hours. The instrument had a second reel of Saranwrap plastic tape which covered the exposed collecting tape at the end of its exposure period.

2.2.2 Radiation Readings Over Land Type Surfaces.

2.2.2.1 Total Exposure[1] Detectors. Film packs, chemical vials, and direct reading dosimeters were used as total exposure detectors. Some of these detectors were placed at all land as well as floating stations. Most of the processing and data reduction was performed by Project 2.1.

2.2.2.2 Gamma Exposure Rate Meters. A device know as "Conrad I" was used by Project 2.2 for the measurement of gamma exposure rates over a range of 1 r/hr to 10^4 r/hr with a time resolution of 5 minutes and 0.05 minutes respectively at these exposure rates. It consisted of an unsaturated ion chamber as the sensing device and an Esterline Angus pen recorder. A second instrument similar to the one above and designed to operate over a range from 0.2 mr/hr to 3600 r/hr, was used by Project 2.63. Project 2.65 used a probe lowered from a helicopter to measure gamma exposure rates at 3 feet above the ground. The probe contained a

1. In this report the word "exposure" will be used to describe the radiation as measured in roentgens.

detector element which was the ionization chamber from a Jordan model AGB-10K-SR survey meter. The output current from the chamber and associated curcuitry flows through the probe wire to the indicating meter mounted in the helicopter. The range of this instrument was from 0.01 mr/hr to 10^4 r/hr.

2.2.2.3 Time of Arrival Detectors. Project 2.63 used a time of arrival detector consisting of an ionization chamber which triggered an 8 day chronometric clock when an exposure rate of 20 mr/hr for a period of a half hour was reached. Subtracting the clock reading at recovery time from the known time since detonation yielded the time of arrival of the fallout.

2.2.3 Radiation Readings In and Above Ocean and Lagoon Water.

2.2.3.1 Survey and Collection Vessels. To meet the objective of collecting fallout and establishing contours over the vast ocean fallout areas, an extensive array of floating and flying instrument platforms was needed. The following summary lists these platforms, but the detailed discussion of the instrumentation aboard will be postponed to Section 2.3.

a. The GRANVILLE S. HALL (YAG-39); GEORGE EASTMAN (YAG-40); and the USS CROOK COUNTY (LST-611) were positioned in the fallout area prior to the arrival and served as completely instrumented collector stations.

b. Two large barges, the YFNB-13 and YFNB-29, and three pontoon rafts were anchored in Bikini Lagoon as fallout collection stations.

c. Fourteen to sixteen skiffs (the number varied with each shot) were moored in the deep ocean north of Bikini Atoll for fallout collection. In addition to the array of skiffs moored in the ocean north of Bikini Atoll, for ZUNI, one skiff was deep moored in the open ocean to the South of the Atoll and for TEWA, 3 skiffs were placed to the West of the Atoll.

d. Two destroyer escorts, the USS MCGINTY (DE-365) and USS SILVERSTEIN (DE-534), and the oceanographic research vessel M/V HORIZON ~~per-~~ were held out of the area until fallout ceased and then performed a radiological survey of the contaminated ocean areas. ~~after fallout had ceased.~~

e. An instrumented landing craft, the LCU-1136, performed a survey of the Bikini Lagoon after fallout from shots CHEROKEE, ZUNI, FLATHEAD, and DAKOTA had ceased.

f. P2V aircraft surveyed the ocean areas after fallout had ceased, measuring the exposure rate in the air above the ocean.

g. On occasion the M/V HORIZON, DE's and P2V aircraft were used to check background radiation before a shot and the effects of ~~air and~~ water currents on the fallout ocean area.

2.2.3.2 Surface ~~Intensity~~ Exposure Rate Readings. A probe furnished by Project 2.62 was trailed in the water on a cable from a boom extending some 25 feet from the side of the YAG's and DE's and from the stern of the M/V HORIZON. The radiation sensing element was about three feet under the surface of the water. The probe consisted of geiger tubes and battery packs encased in one-quarter inch wall steel tubing. Two sensing heads were designed for the probe, one for detecting low level radiation down to background and the other with less sensitive tubes to be used at levels as high as 100 r/hr. The data from the probe was recorded aboard the ship on a chart recorder. While surveying, the probe was towed and a continuous recording of exposure rate made.

Also mounted at the end of the boom ~~in~~ on the two YAG's was a Project 2.64 scintillation detector which was used to obtain readings of the radioactivity as observed looking down from approximately 25 feet above the surface of the water. This instrument utilized a plastic phosphor and covered a range from 0.01 to 1000 mr/hr. The current output, which was proportional to the logarithm of the exposure rate, was recorded on an Esterline Angus strip chart recorder. BEST AVAILABLE COPY

P2V aircraft were instrumented by Project 2.64 with a plastic phosphor detector and associated recording equipment to measure the exposure rate in the air above the ocean. These readings, whenproperly converted, correspond to the exposure rate in the surface water layer. The data was recorded in uncorrected form on a chart recorder. It was also corrected automatically to a surface reading and recorded on a SAN BRUNO FRC magnetic tape. The sensing unit was shielded to minimize the effect of contamination on the aircraft and the resulting angular response was measured and the readings appropriately corrected.

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2.2.3.3 Intensity Versus Depth Profile. The probe described in Section 2.2.3.2 was also used to obtain exposure rate vs depth profiles. It contained a pressure sensing element to record the depth at which the instrument operates. The cable which supported the probe was a three conductor armored cable, so that the signals from the radiation and pressure sensing elements in the probe traveled up through the conductors and were recorded on an XY recorder aboard ship. The equipment for making depth profiles was designed for a maximum depth of 400 meters except on the M/V HORIZON where it could attain a maximum depth of 800 meters.

Penetration recorders designed to trigger upon arrival of fallout at the surface and to record the gamma exposure as a function of time thereafter at 20, 40, 60, 80 and 100 meters in depth, were installed on some of the deep moored skiffs.

2.2.3.4 Analysis of Water Samples. All survey ships were equipped to take surface water samples using polyethylene buckets lowered over the side. In addition, the M/V HORIZON was equipped to take samples at depths with standard Nansen bottles. Detailed analyses of these samples were then made by Projects 2.62, 2.63, and 2.64.

Ex Insert #1 2.2.3.5 (page 37)

2.2.4 Radiation Readings in the Nuclear ~~Cloud~~ mushroom. Project 2.61 undertook to measure the radiation in the nuclear ~~cloud~~ mushroom with pressure ion chambers borne by single stage rocket propelled atmospheric sounding vehicles (ASP). The exposure rate data was telemetered to essentially duplicate receiving-recording stations on the USS KNUDSON (APD-101) and

(Insert #1)

2.2.3.5 Fallout Decay Tanks. In order to determine the ~~effective~~ decay of the fallout material in the ocean water as measured by the survey probe, a decay tank 6 feet in diameter and 6 feet deep was placed on the deck of the YAG 39. The tank was filled with ocean water before the arrival of fall-out and a probe was placed in it. The tank then collected fallout and was agitated to maintain a uniform distribution. The probe readings gave data on the buildup and effective decay of the activity.

A tank 5 feet in diameter and 5 feet deep was used on the deck of the M/V Horizon in a similar fashion. However, in this case, the tank was filled with contaminated ocean water as soon as it was obtainable after the M/V Horizon began making the oceanographic survey, which was after the fall-out in the area had ceased. To prevent the fallout particles from settling out or adhering to the sides of the tank, the water was treated with sodium silicate and hydrochloric acid to form a gel as soon as possible after it was obtained. The "gelling" was not completely successful and the water was also mixed mechanically. Readings from the probe in this tank then gave data on the decay.

Site NAN where the signals were recorded on magnetic tape. Figure 2.1 is a picture of an ASP on its launcher. This rocket is 6 1/2 inches in diameter and 147 1/2 inches long. On the shots CHEROKEE, ZUNI, and NAVAJO, two salvos of six rockets each were fired from the launchers near the center of HOW Island. The first salvo was fired commencing at H/7 minutes and the second salvo was fired at H/15 minutes. Four rockets were fired in one salvo at H/7 minutes on shot TEWA. The rockets were fired along trajectories which would best give data on the relative activity in the cloud and stem and the distribution of activity in each of these. Trajectory data as shown in Figure 2.2 from a limited number of previous firings of the ASP were used to calculate the position of the rockets in the cloud as a function of time for the predetermined elevation and azimuth of the launcher.

In addition, Project 2.66 manned aircraft were flown into the radioactive cloud as early as H/15 minutes on certain shots and obtained further data on the distribution of activity in the cloud.

2.3 OPERATIONS

2.3.1 Land Stations. The location of the land stations at Bikini Atoll are shown in Figure 2.3. All instrumented islands had both incremental and gross collectors. Figure 2.4 is a picture of a representative Project 2.65 land station. From three to five days before each shot were required for preparing and checking the instrumentation at the stations. The samples from the stations were recovered after each shot as soon as radiation levels permitted. Some preliminary analyses of samples were

PROPELLANT.........Single grain GCA201A stabilized ammonium perchlorate oxidizer and LP33 thiakol base.

TOTAL IMPULSE......31,000 pound-seconds.

BURNING TIME.......5.8 seconds.

WEIGHT.............Pre-launch - 245 pounds.
Burn-out - 100 pounds.

MAXIMUM VELOCITY...~5,000 feet/second.

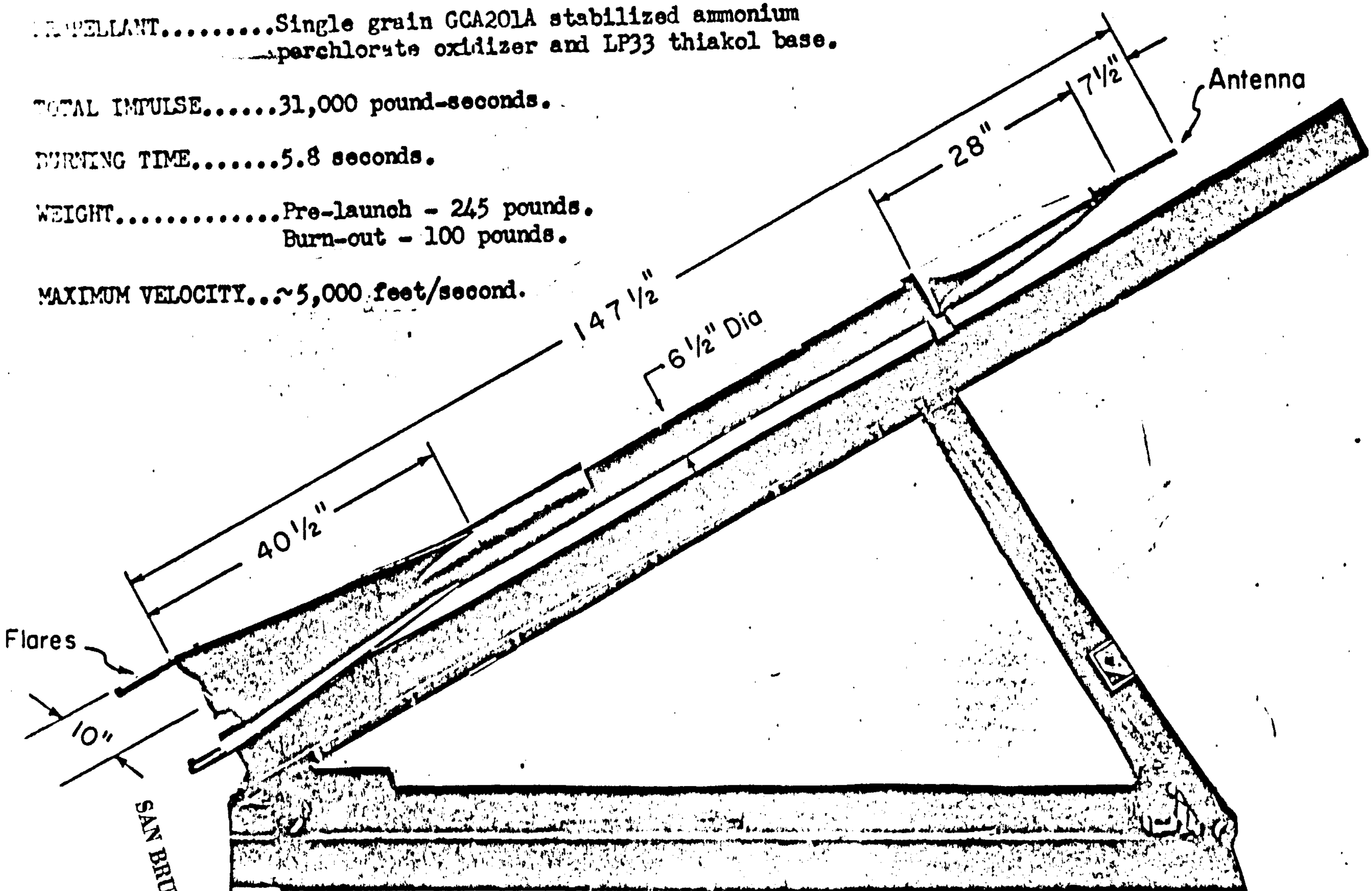

Figure 2.1 Project 2.61 A3P rocket on launcher.

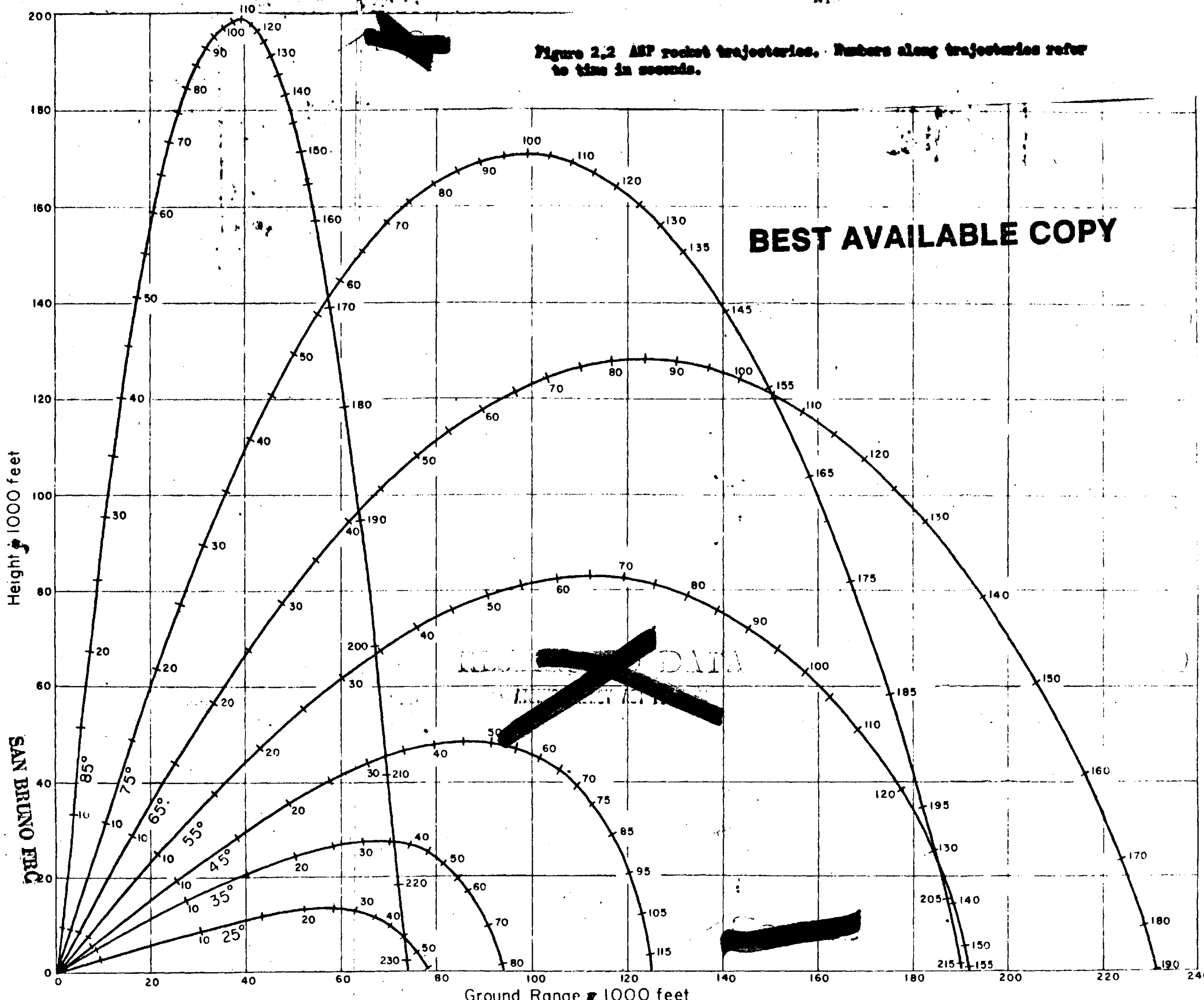

Figure 2.2 ASP rocket trajectories. Numbers along trajectories refer to time in seconds.

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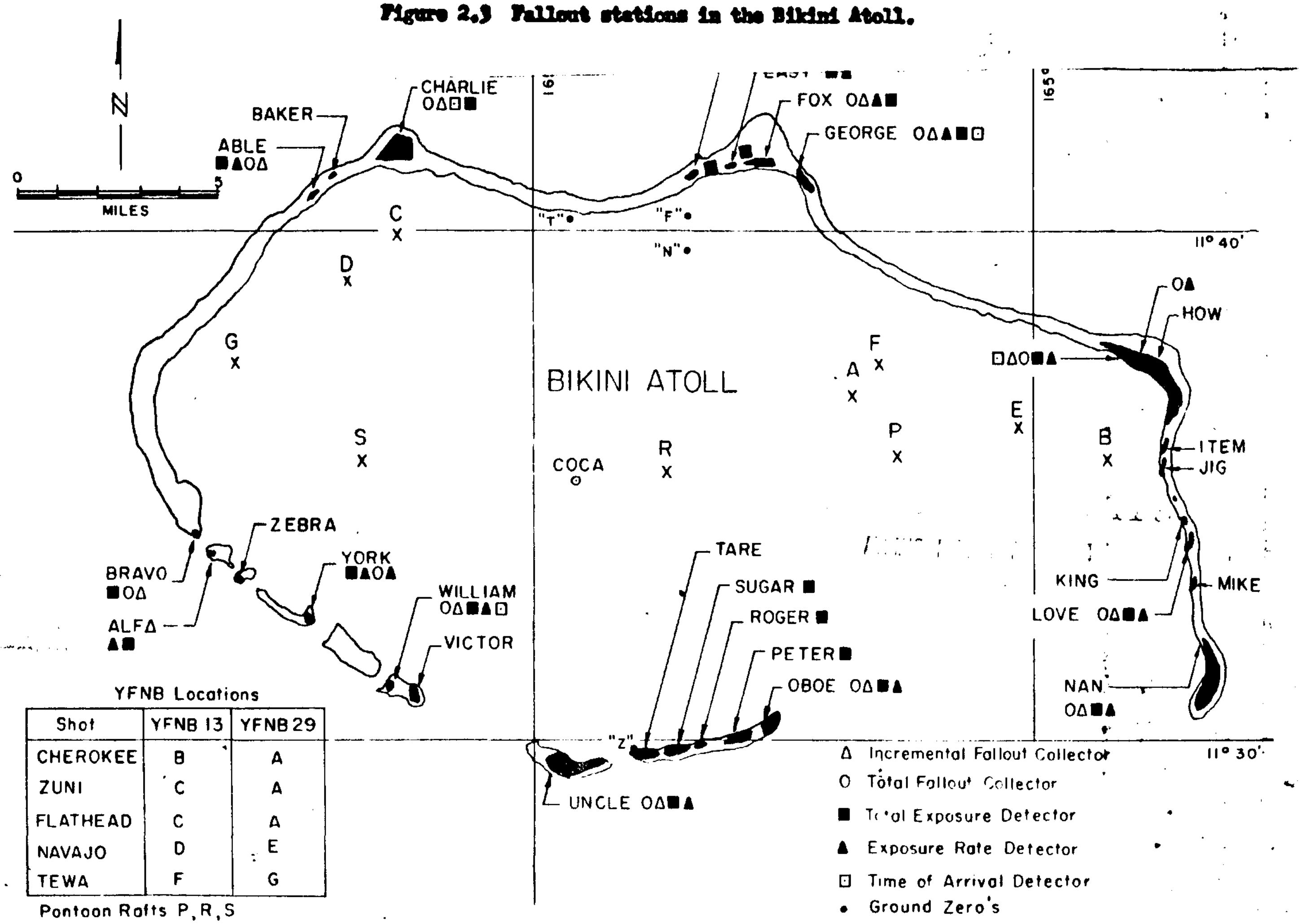
Figure 2.3 Fallout stations in the Bikini Atoll.



YFNB Locations

Shot	YFNB 13	YFNB 29
CHEROKEE	B	A
ZUNI	C	A
FLATHEAD	C	A
NAVAJO	D	E
TEWA	F	G

Pontoon Rafts P, R, S

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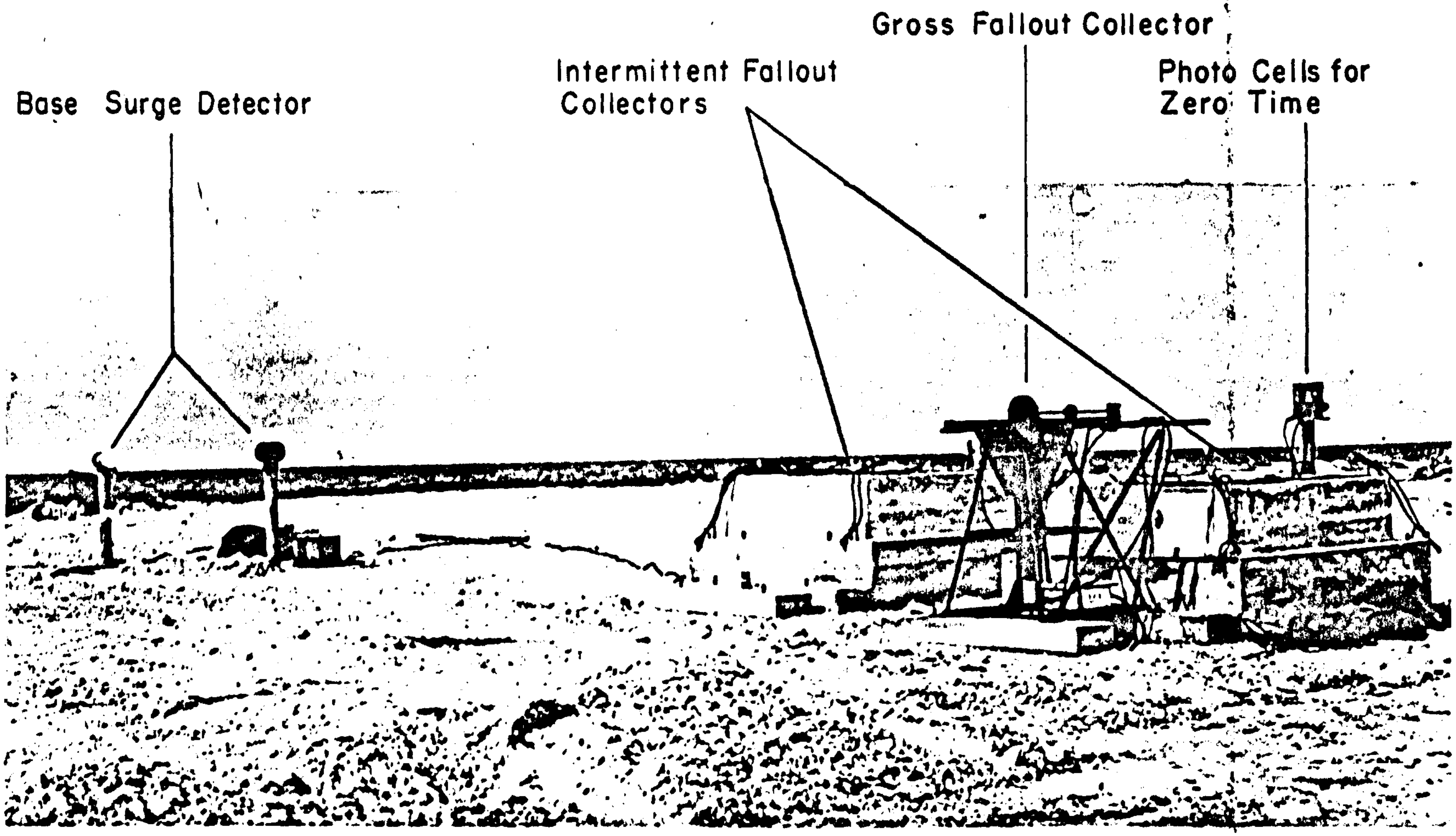


crop to remove base surge detector

Figure 2.4 Representative land station of Project 2.65 on Site OBOE.

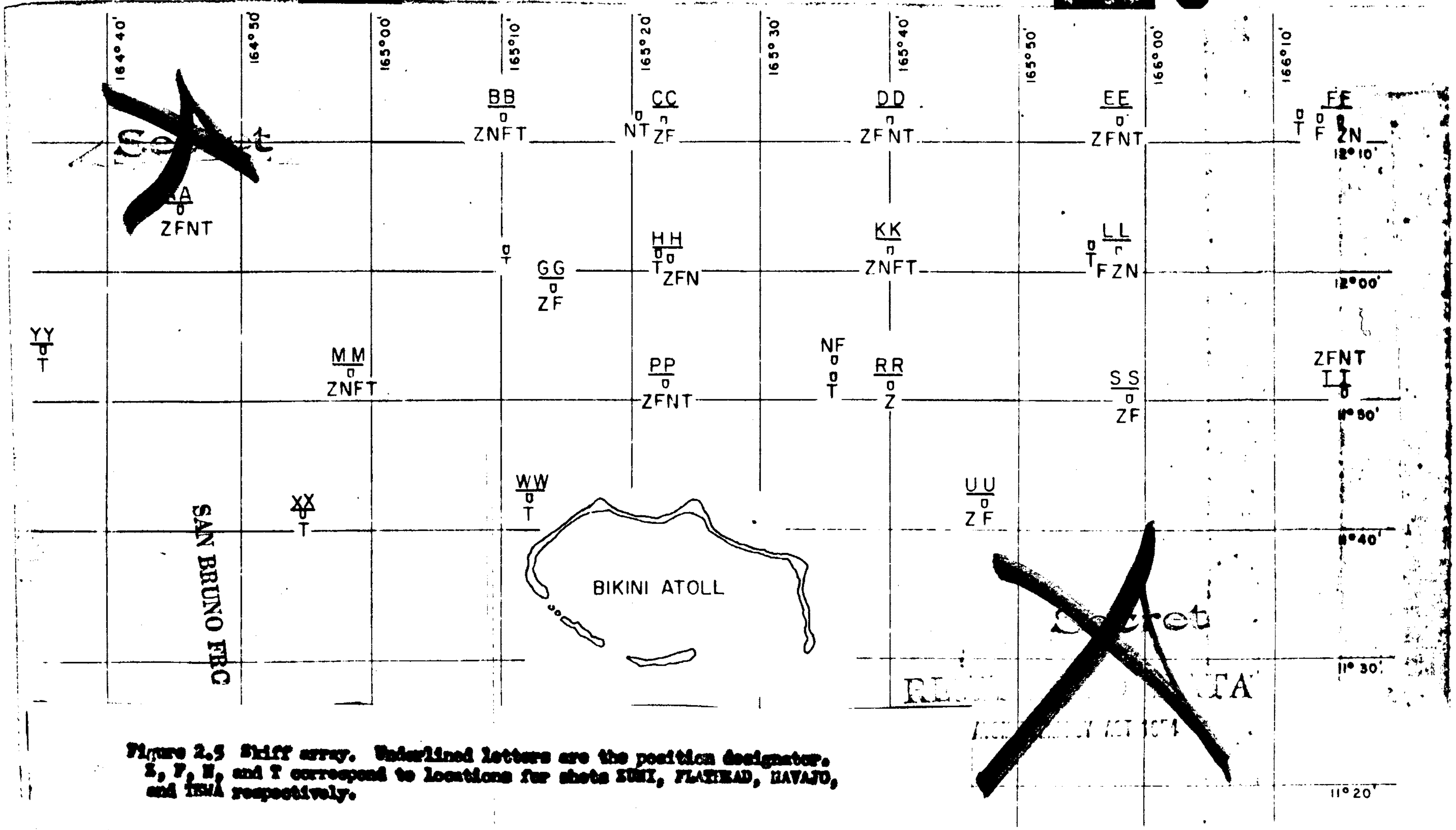
made at Site FLUTE and the remainder of the samples were placed aboard the fly-away aircraft for complete analyses in laboratories in the United States.

2.3.2 Moored Stations (YFNB Barges, Rafts, and Skiffs; see Figures 2.3 and 2.5 for locations). Two YFNB barges were anchored in Bikini Lagoon at positions which varied with shot location. These barges were completely instrumented by Project 2.63 with equipment for collecting fallout material and recording radiation readings in both incremental and total form. In addition other projects placed equipment aboard for correlation.

YFNB-29 had one instrument tower at each end of the barge. The towers were separated by a distance of 250 feet which was considered to be far enough apart to indicate the extent of variation of the fall-out within a small region. Three pontoon rafts (each 15 feet by 16 feet) were placed at positions as shown in Figure 2.3 for all shots. Instrumentation for time of fallout arrival, total collection of fall-out material, and total exposure reading were placed on these rafts.

Skiffs were deep moored in the ocean north of Bikini Atoll as shown in Figure 2.5. Each skiff contained the same general type instrumentation as was placed on the rafts. However, in addition, penetration recorders were placed on some skiff installations. Figure 2.6 shows the detail of a skiff station. Beginning two to three days after a shot the USS SIOUX was used to recover the skiffs, collect the samples and data, and re-arm the skiff for the next shot.

[redacted] [redacted]



-44-

Figure 2.5 Skiff array. Underlined letters are the position designator. Z, F, N, and T correspond to locations for shots ZUNI, FLATHEAD, NAVAJO, and TEWA respectively.

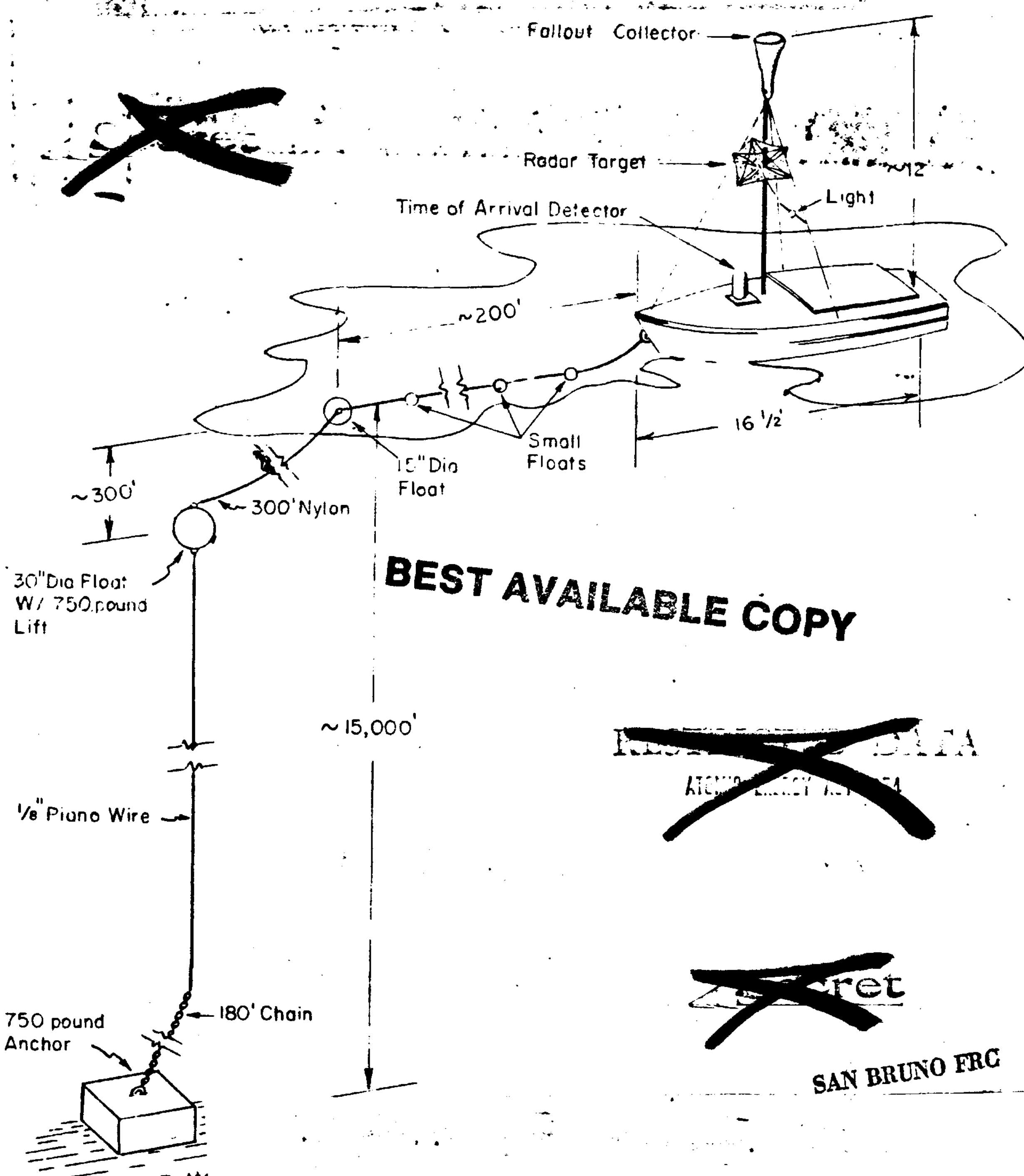


Figure 2.6 Method devised by Project 2.62 to deep moor skiffs in open ocean.

2.3.3 YAG's and LST. The YAG-39, YAG-40 and LST-611 were the most completely instrumented stations in the fallout program. The vessels were designed so they could be maneuvered into key positions in the fallout area for each shot. They were directed to such positions by calculations based on known and predicted wind data. These vessels were equivalent to land collection stations and were necessary because of the very limited land areas at the PPG. These ships were manned and when fallout arrived, the small crew went to a shielded room in each ship and controlled the ship from there. The fallout instrumentation was designed to be operated from this control room and much of the data was recorded there. Figure 2.7 shows the details of the instrumentation on the YAG's. A shielded laboratory was installed on YAG-40 to make very early measurements on decay, spectrum, etc. of the fallout material.

2.3.4 P2V Aircraft and Helicopters. P2V aircraft equipped with scintillator detectors flew at altitudes from 200 feet to 400 feet over the water areas soon after fallout was complete. On shot day, aircraft surveyed the areas near Bikini Atoll after the fallout was down in these areas. On succeeding days, one or more planes surveyed the ocean area farther out as fallout ceased. Prior to shots NAVAJO and TEWA, a P2V aerial survey was made of the area to the west of Bikini to check the area of radioactive effluent from the Bikini Lagoon.

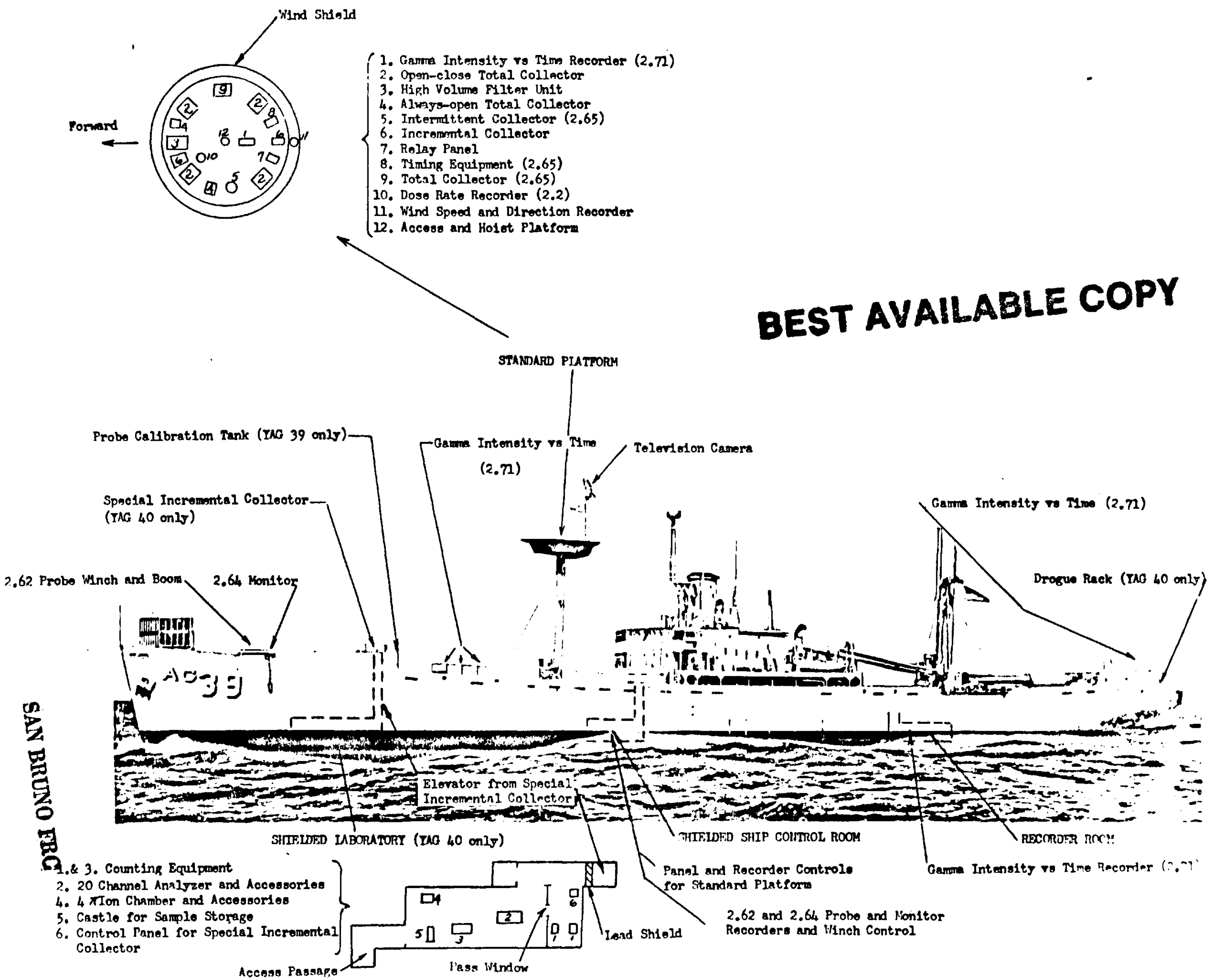


Figure 2.7 ~~USNS~~. GRANVILLE S. HALL, YAG 39. Fallout collection stations are for Project 2.63 unless otherwise noted. Ship operation was under the direction of Project 2.10.

Radiation exposure rate measurements on land surfaces were made by using a probe attached to a cable and lowering the probe from a helicopter to the ground. Figure 2.8 shows some of the details of how these measurements were made. The helicopter hovered over the island at altitudes from 500 to 1,000 feet and therefore this technique permitted very early measurements to be made without excessive radiation dosage to personnel.

<u>2.3.5 Two DE's, M/V HORIZON, and LCU-1136</u>. While the YAG's and LST were located at key positions in the fallout pattern at the time of fallout, the two DE's, M/V HORIZON, and LCU-1136 were not directed into the pattern until the fallout was complete. Once the fallout had ceased, the two DE's were dispatched into the area to make passes across it and establish the boundaries of the fallout pattern as well as to make a detailed survey of the pattern within these boundaries. The M/V HORIZON was a slower vessel and made a somewhat more detailed oceanographic survey in the fallout area and thus complemented the more rapid surveys of the two DE's. The LCU-1136 made oceanographic type surveys of Bikini Lagoon while the other three vessels covered the vast areas of the fallout in the ocean after the five shots of interest to the fallout program. All of the survey vessels made surface and depth profile measurements of the activity and collected water samples. Just prior to NAVAJO, an oceanographic survey was made to determine background activity which might mask the low levels anticipated from this shot.

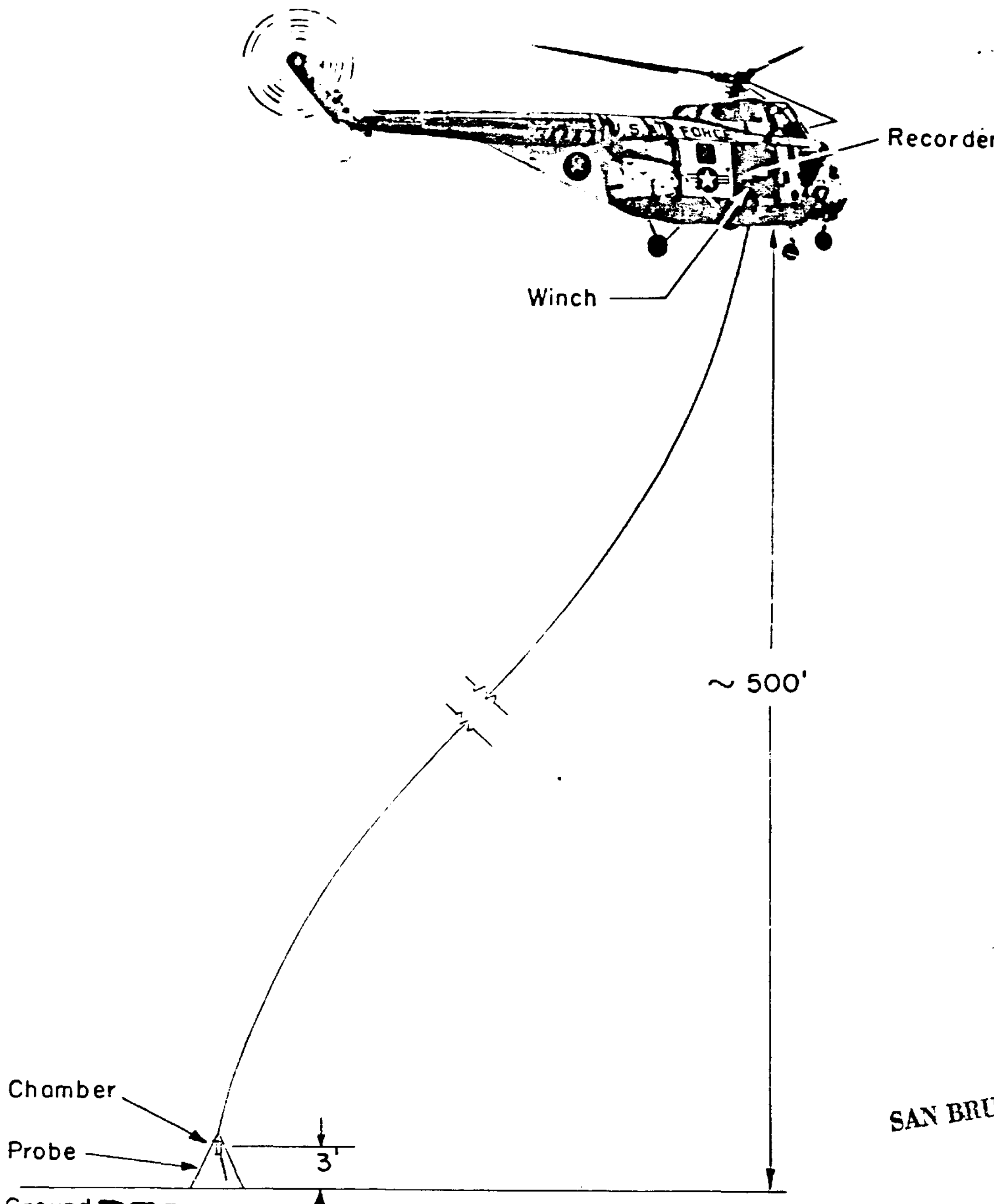


Figure 2.8 Arrangement of Project 2.65 probe for measurement of gamma dose rates.

2.3.6 Program Two Control Center. The Program Two Control Center was located in the Flag Communications Center aboard the Task Force SEVEN Command ship, the USS ESTES. The primary reason for locating the Center here was the availability of communications required for contact with the ships and aircraft.

Meteorological data and predictions were obtained and on the basis of these a ~~static~~ particle fall plot was constructed for the H-hour wind predictions. Work on these plots was begun on D-1 when the first ship was directed into the area where fallout was expected. This plot was revised as later meteorological data and predictions were received. A constant revision of the plot was necessary since the LST and the two YAG's had to leave the Bikini Lagoon on D-1 in order to arrive at locations in the predicted fallout area. The time variation of the winds also resulted in minor changes in the positions of the YAG's and LST-611 being made after shot time in order that the ships be in the most favorable locations when fallout arrived. Direct communications between the Program Two Control Center and the project ships permitted the desired close control on the positioning of the ships.

The P2V aircraft, based at Kwajalein, began their survey around Bikini Atoll on shot day. From the Control Center they were given instructions regarding their flight paths over the area, as far as possible avoiding regions where fallout might still be coming down.

Once the general area of close-in fallout was delineated by the P2V aircraft, the two YAG's and the M/V HORIZON were directed into this area to begin an oceanographic survey, and the LCU-1136 began a survey of Bikini lagoon.

By relaying to the ships successive courses and points to which to proceed and receiving reports from the ships on their speed and position fixes, a detailed plot of the trace of each ship was maintained in the Control Center. A similar plot was maintained for the flights made by the P2V aircraft.

Fallout data from the various ships and aircraft were reported directly to the Program Two Control Center. Here the information was recorded in data books by the various projects and also placed on a Master Operations Plot. In addition to the data obtained from the ships and aircraft, radiation readings on the islands in Bikini Atoll were obtained from the group performing the atoll aerial survey and from the *Task Group 7.1* RadSafe organization. These data were also recorded on the Master Operations Plot.

The Control Center continued in operation for as long as five or six days after an event while the survey ships were completing their detailed oceanographic survey of the fallout area.

2.3.7 Correlation Measurements. The instrumentation was very carefully correlated between the various projects. Project 2.65, which had fallout collection and radiation reading instrumentation at land stations, placed the same type of instrumentation aboard the two YAG's and one of the YFNB barges. Similarly, Project 2.62, which designed the instrumentation aboard the two YAG's, LST, and YFNB barges installed a major land station at the northern tip of HOW Island for cross calibration. This station consisted of a tower containing a major array of instrumentation very similar to the instrumented towers on the YAG's, LST and YFNB barges.

CHAPTER 3

RESULTS

3.1 THE LAND SURFACE BURST

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3.1.1 Zuni.

3.1.1.1 Introduction. The Zuni Shot was fired at the surface of Site Tare on 28 May 1956, at 0556M. The yield of the weapon was measured to be approximately [redacted] of which [redacted] It has therefore been assumed that all radiation readings presented for fallout from this device should be

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These values form the basis for comparison between different weapons

The environment of the Zuni weapon is illustrated in Figure 3.1 on which is also drawn the outline of the crater formed by the detonation. Clearly a large fraction of the crater was in land and reef, although a part of it extended into the deep lagoon water. Zuni was considered as a land surface shot, although the proximity of the deep lagoon introduced minor modifications which may make it similar to a shallow harbor burst.

3.1.1.2 Distribution of Activity in the Stabilized Cloud. Measurements of the radiation field at various positions in the nuclear cloud were made at H+7 minutes and H+15 minutes by the Project 2.61 rockets. The exposure rate data as recorded on magnetic tape have been subjected to preliminary analysis. The preliminary reduction of this data to information concerning the distribution of active material in the cloud is subject to the following limitations:

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(a) The read-out circuit is not as elaborate and free from noise interference as that to be used in the final analysis.

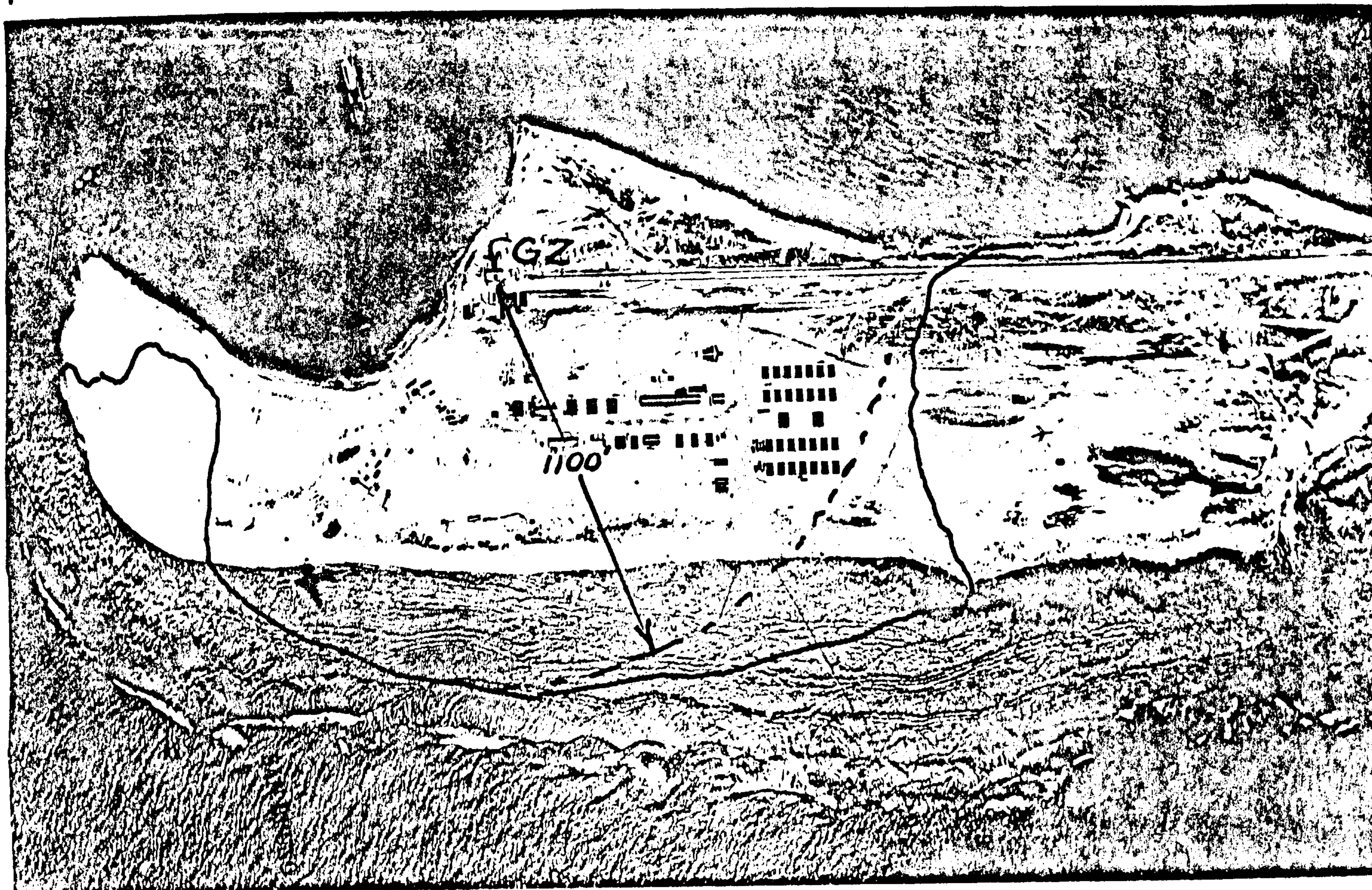


Figure 3.1 Aerial View of Site Tare With Overlay of the Zuni Crater.

(b) The identification of a particular rocket track with a known exposure rate versus time record is quite certain for some traces, but not in the case of others. However, the main conclusions to be drawn from the data will probably be insensitive to the exact identification of all the traces.

(c) The rocket trajectories are based on the data available in the field and may be improved by subsequent analysis of data from test firings.

(d) The calibration of the ion chamber detectors at high exposure rates is not linear and such readings may have to be altered using better calibration curves.

(e) There is some uncertainty in the zero time on a number of records as related to the launch time of the rockets.

It is desirable to present the data in such a form that it demonstrates the concentration of source activity at various positions in the cloud. The exposure rate readings at a particular location actually represent the cumulative effect of many sources distributed over a volume whose dimensions are of the order of the attenuation length for the gamma rays. This attenuation length is inversely proportional to the density of the air and varies from about 400 feet at sea level to 1,400 feet at an altitude of 40,000 feet, and to 10,000 feet at an altitude of 80,000 feet. Therefore, the observed exposure rates actually measure average distributions of activity over volumes having the given dimensions. Since these volumes, particularly near the bottom of the cloud, represent a small part of the total cloud volume, this method of measurement of the activity is meaningful. In presenting the data, the observed exposure rate readings were multiplied by the ratio of the air density at the data point to the sea level density. The result represents the exposure rate that would have been observed had the same density of sources been present in air at sea level pressure and temperature, and therefore is proportional to the activity concentration. A crude calculation predicts that a distribution of 1 curie/m^3 under these conditions would produce an exposure rate of about 1,200 r/hr.

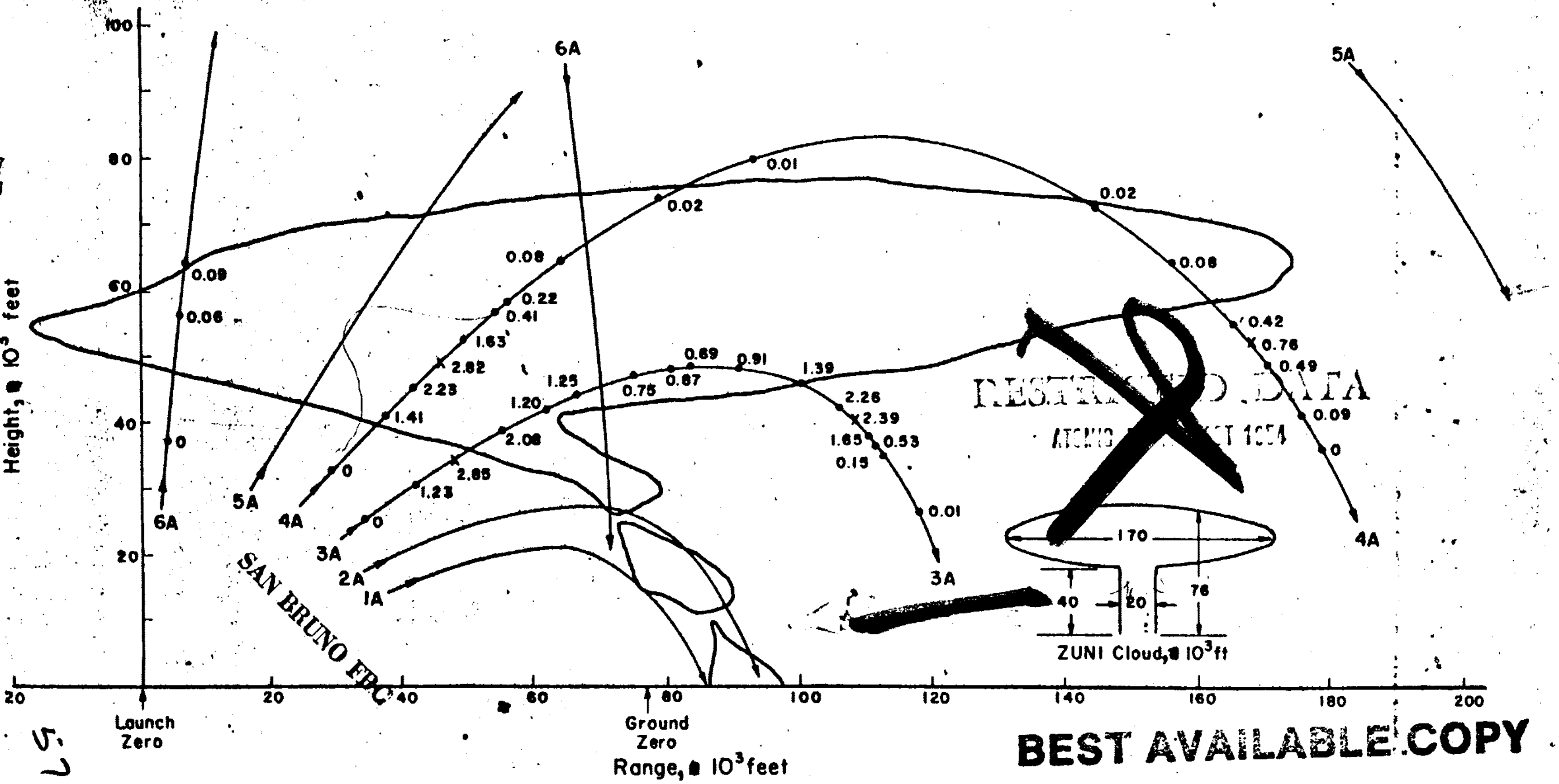
Subject to the limitations discussed above, the reduced exposure rate readings are presented in Figures 3.2 and 3.4 for the 7 and 15 minute salvos respectively. The mushroom outline presented is a cross-section in the plane of the rocket trajectories which has been constructed on the basis of the assumption that the cloud and stem move from zero time to rocket firing time under the influence of the measured H-hour winds. Figures 3.3 and 3.5 represent views along the rocket trajectories which indicate where the plane of the trajectories intersected the cloud and stem. The assumed mushroom dimensions are illustrated in the inset in Figure 3.2 which represents a mushroom undisturbed by wind motion. The cloud was constructed by scaling up the dimensions of some photographs of the Dakota cloud [redacted] guided by visual observations and size versus yield data from previous operations (Reference 10).

Further data is also available from the Project 2.66 aircraft penetrations, but these were taken at appreciably later times. The observed exposure rate readings have been extrapolated to H+15 minutes using a $t^{-2.0}$ expression 1/ as determined by previous aircraft penetrations into

1/ The measurements performed at Operation REDWING indicate an exponent of 1.7 to be more appropriate. However, 2.0 has been used in this report.

Figure 3.2 Zuni Cloud at H+7 Minutes in the Plane of the Rocket Trajectories. Readings along trajectories are corrected to sea level and are in units of 10^3 r/hr. Peak readings are denoted with an x.

[redacted]



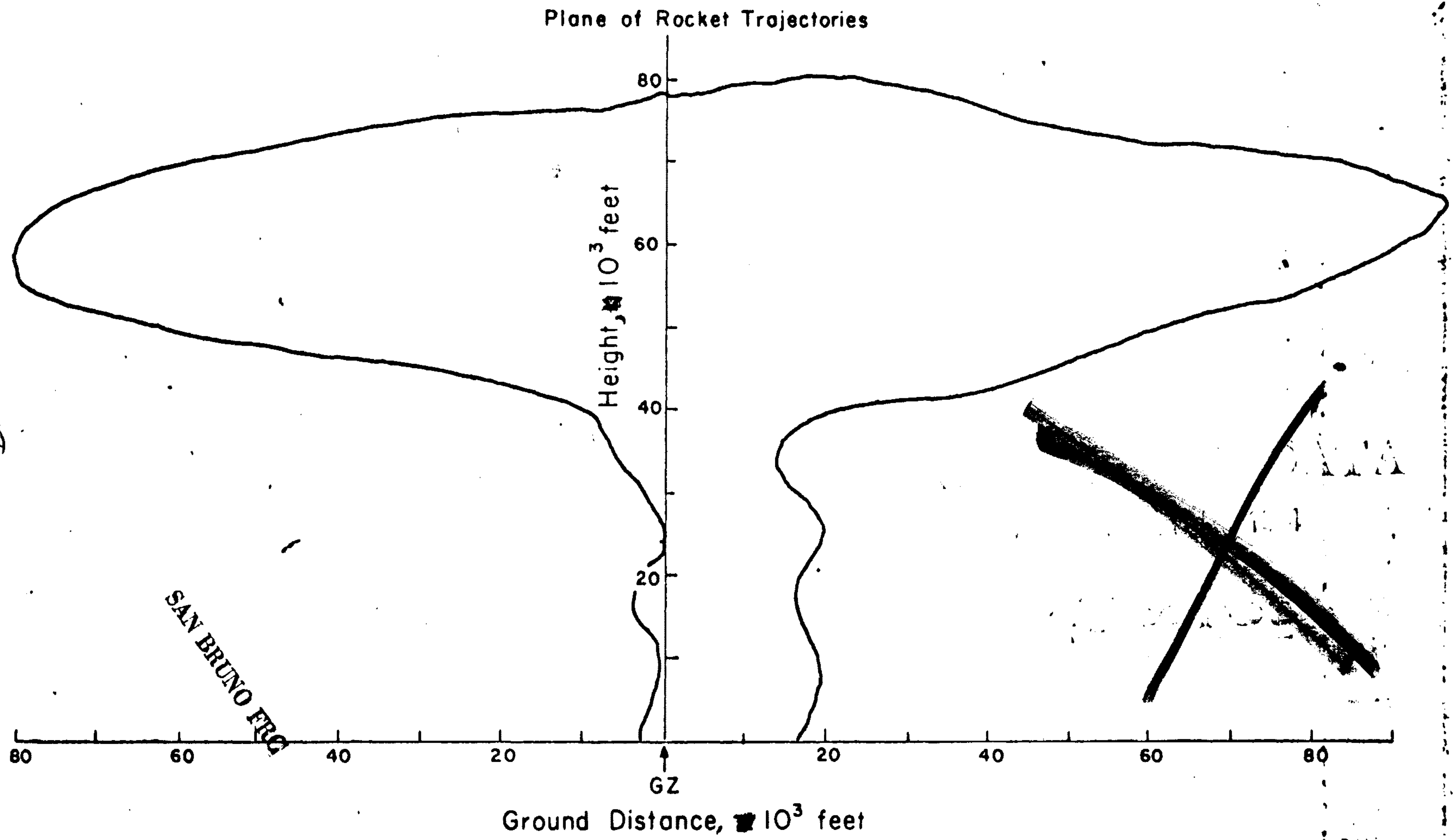


Figure 3.3 Looking Along Plane of H+7 Minute Rockets Toward Zuni Cloud.

-58-

Figure 3.4 Zuni Cloud at H+15 Minutes in the Plane of the Rocket Trajectories. Readings along trajectories are corrected to sea level and are in units of 10^3 r/hr. Peak readings are denoted with an x.

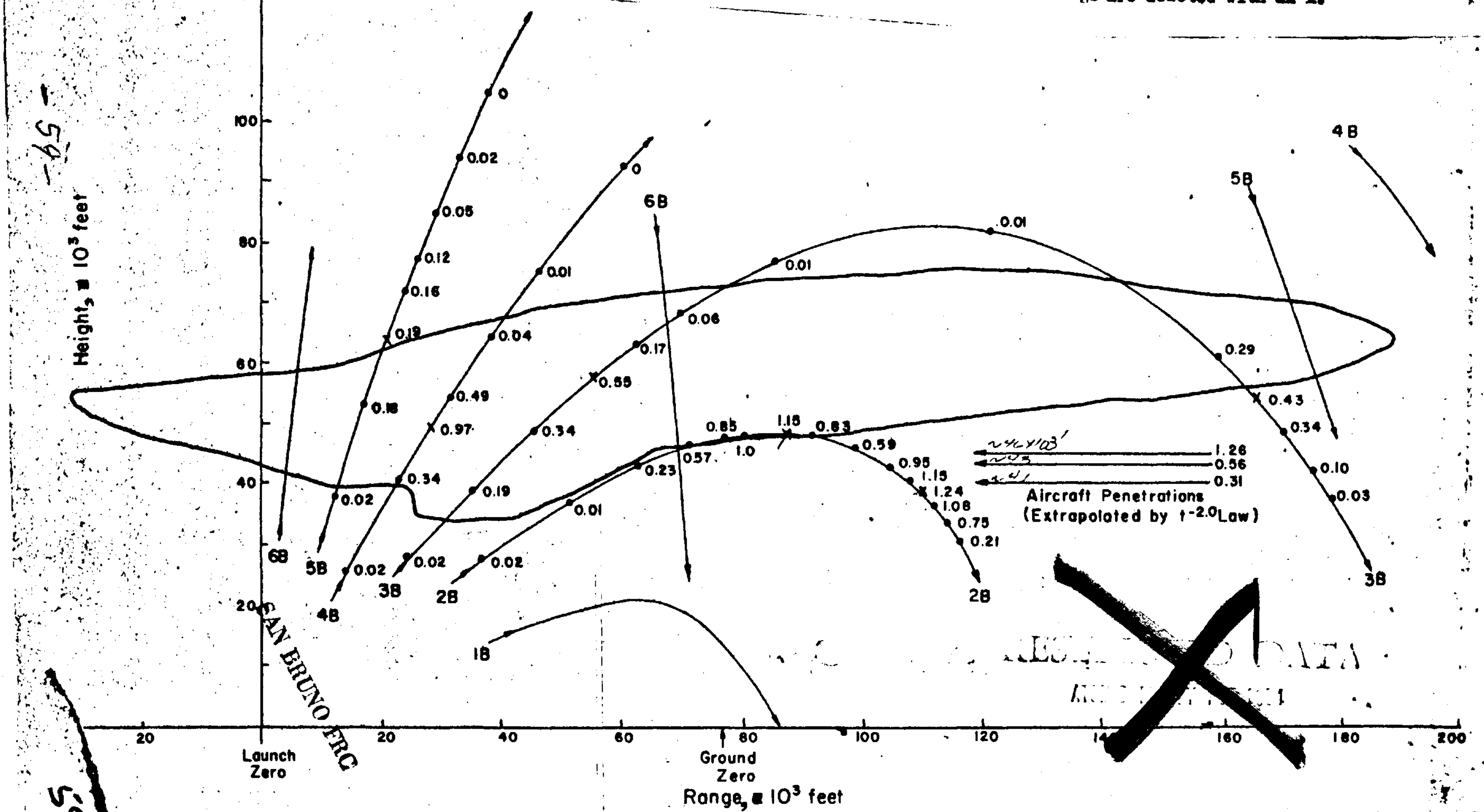
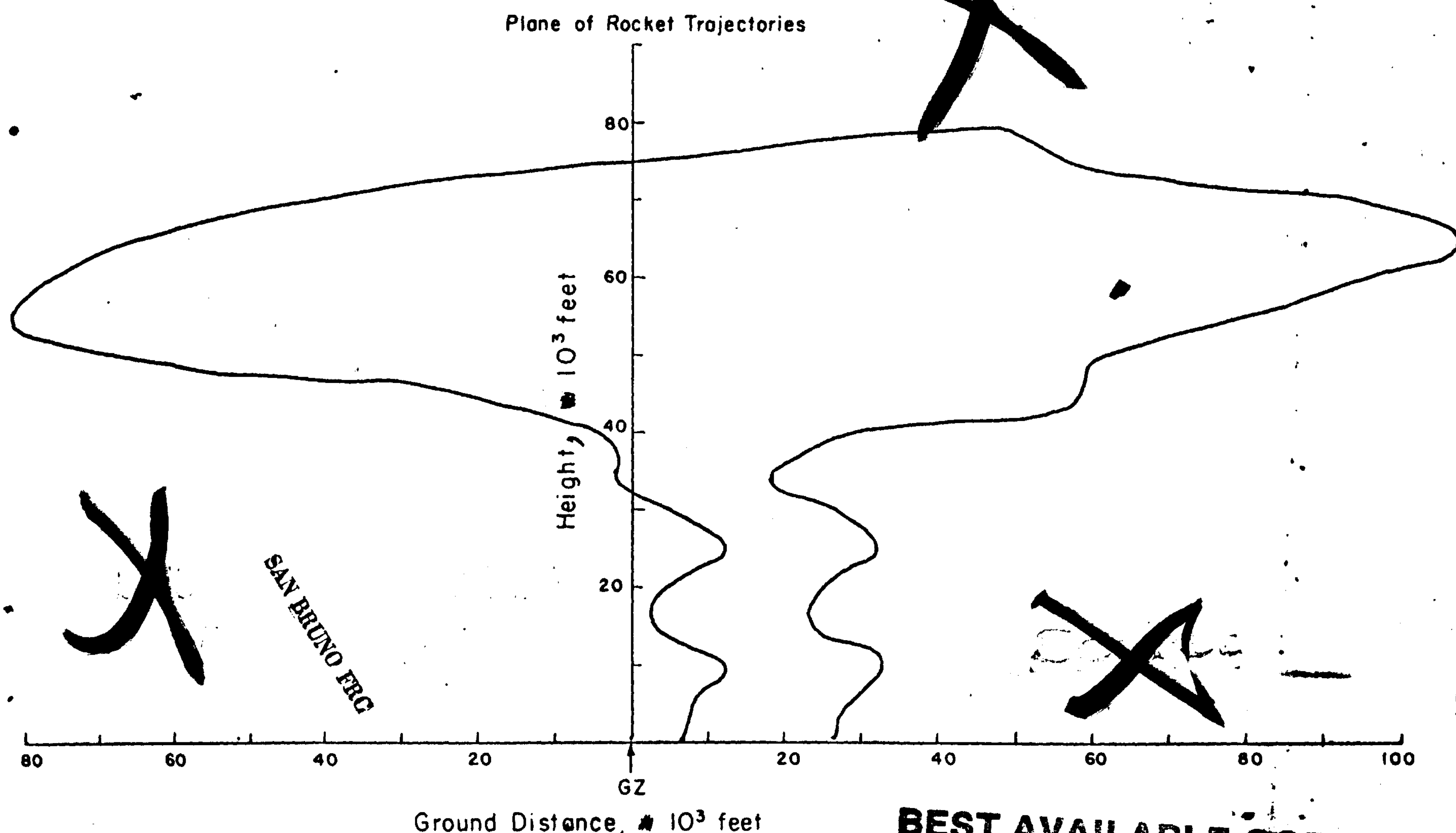


Figure 3.5 Looking Along Plane of H/15 Minute Rockets Toward Zuni Cloud.



the mushrooms from somewhat lower yield detonations. These readings have been included in Figure 3.4, but must be considered tentative subject to uncertainties in the decay factors and the aircraft position relative to the main cloud.

3.1.1.3 Particle Fall Plot. (See Appendix B.) Figure 3.6 represents the particle fall plot for the winds measured at and after shot time for the Zuni event. This plot represents the position on the surface at which a particle would arrive if it originated at a given altitude above surface zero. The plot has been constructed taking into account the time and space variation of the wind pattern, but is subject to the following limitations:

(a) The continuous vertical line source above ground zero was approximated by increments at 5,000 feet levels.

(b) The wind velocity at a 5,000 feet level was assumed to represent the average velocity in the 5,000 feet interval centered at that level.

(c) The particles were assumed to drift with the local wind and to fall as governed by gravity and a typical air density and temperature versus height structure.

(d) The effect of vertical air motions on particle fall rates has been neglected.

(e) The space variations of the wind profile were deduced by a cursory examination of the Eniwetok and Rongerik winds and the synoptic charts which were constructed twice daily. A more detailed meteorological analysis of the air motions would probably introduce some slight modifications.

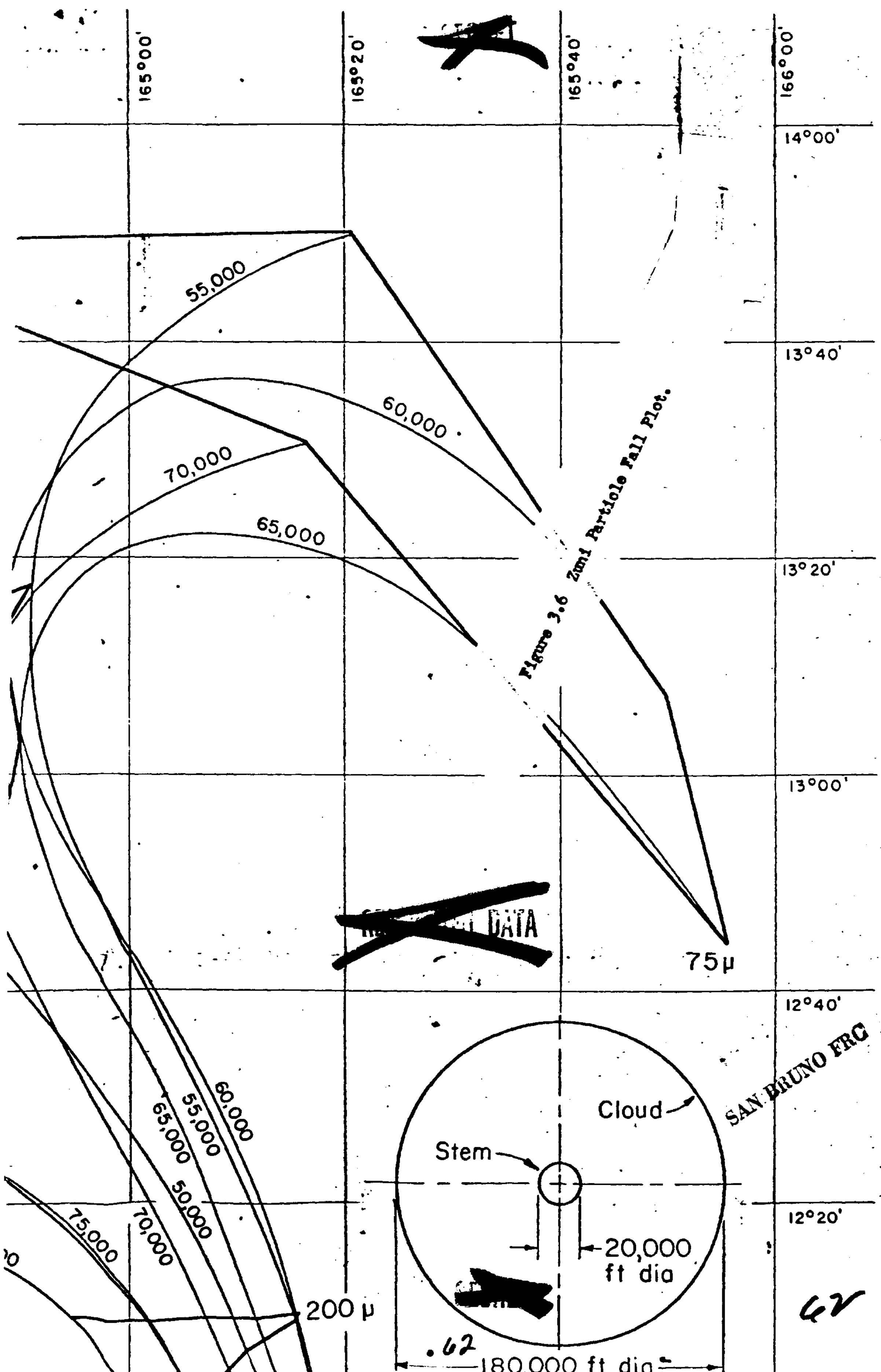
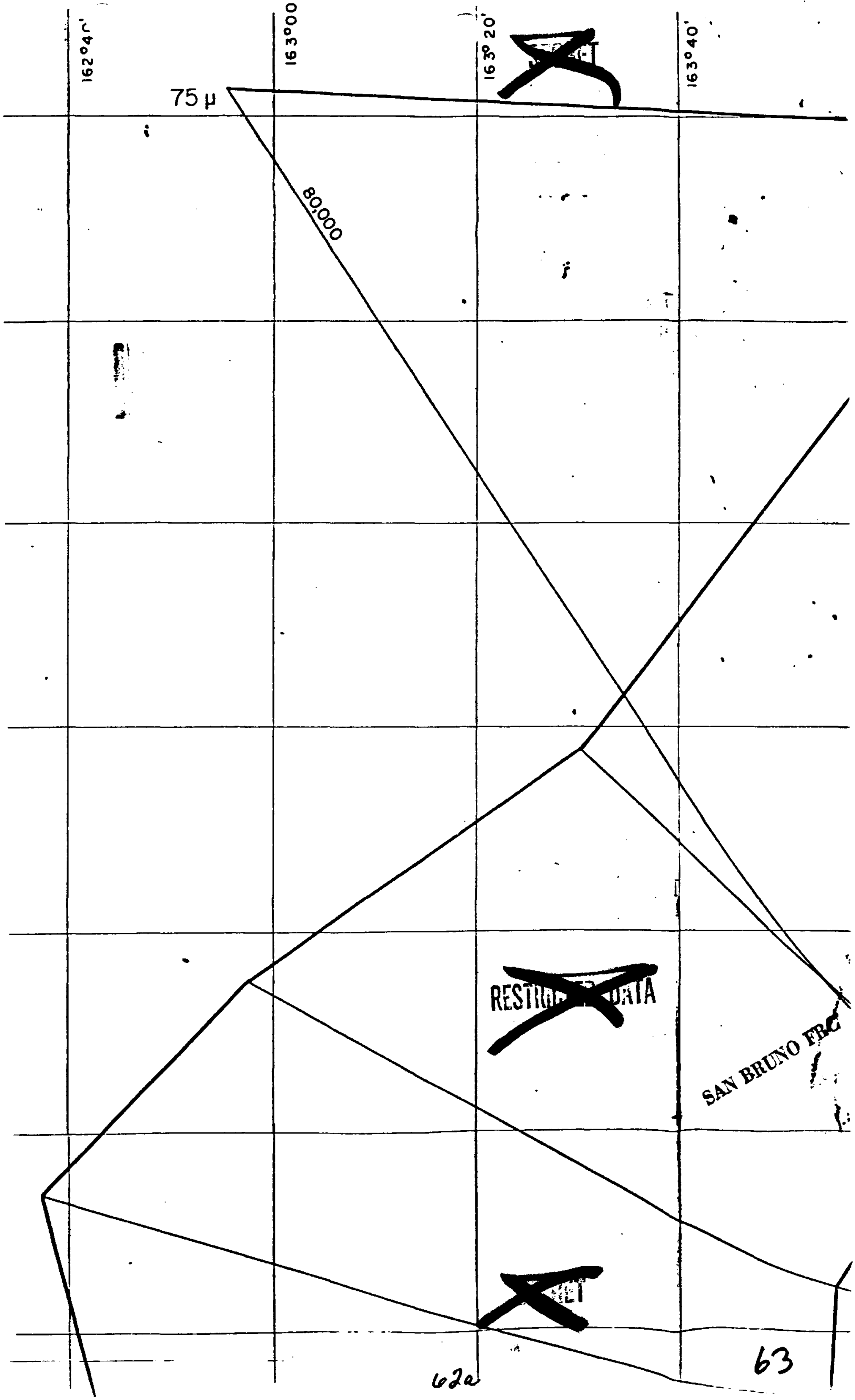


Figure 3.6 Zuni Particle Fall Plot.


162°40'
163°00
163°20'
163°40'
75 µ
80,000
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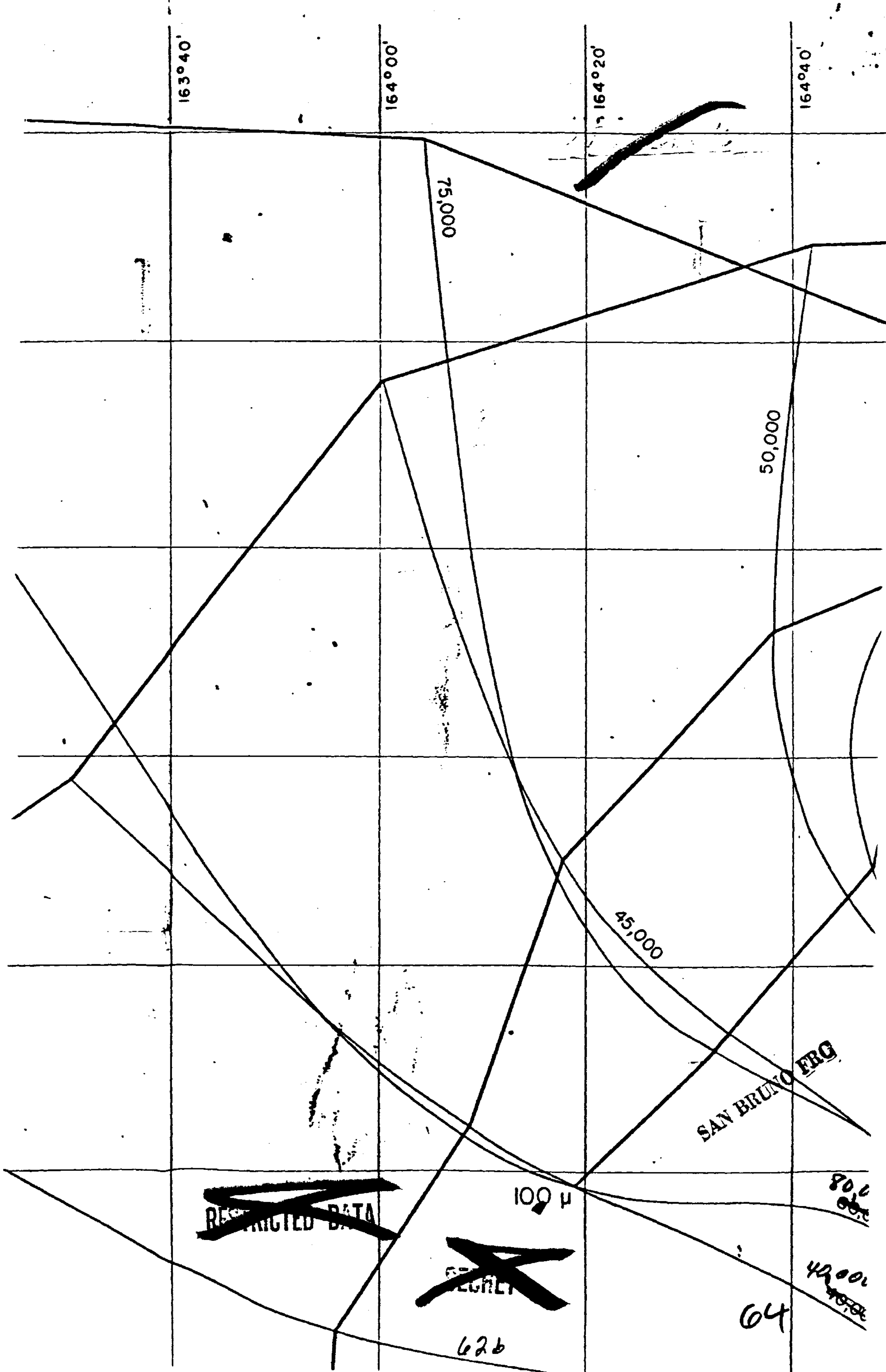
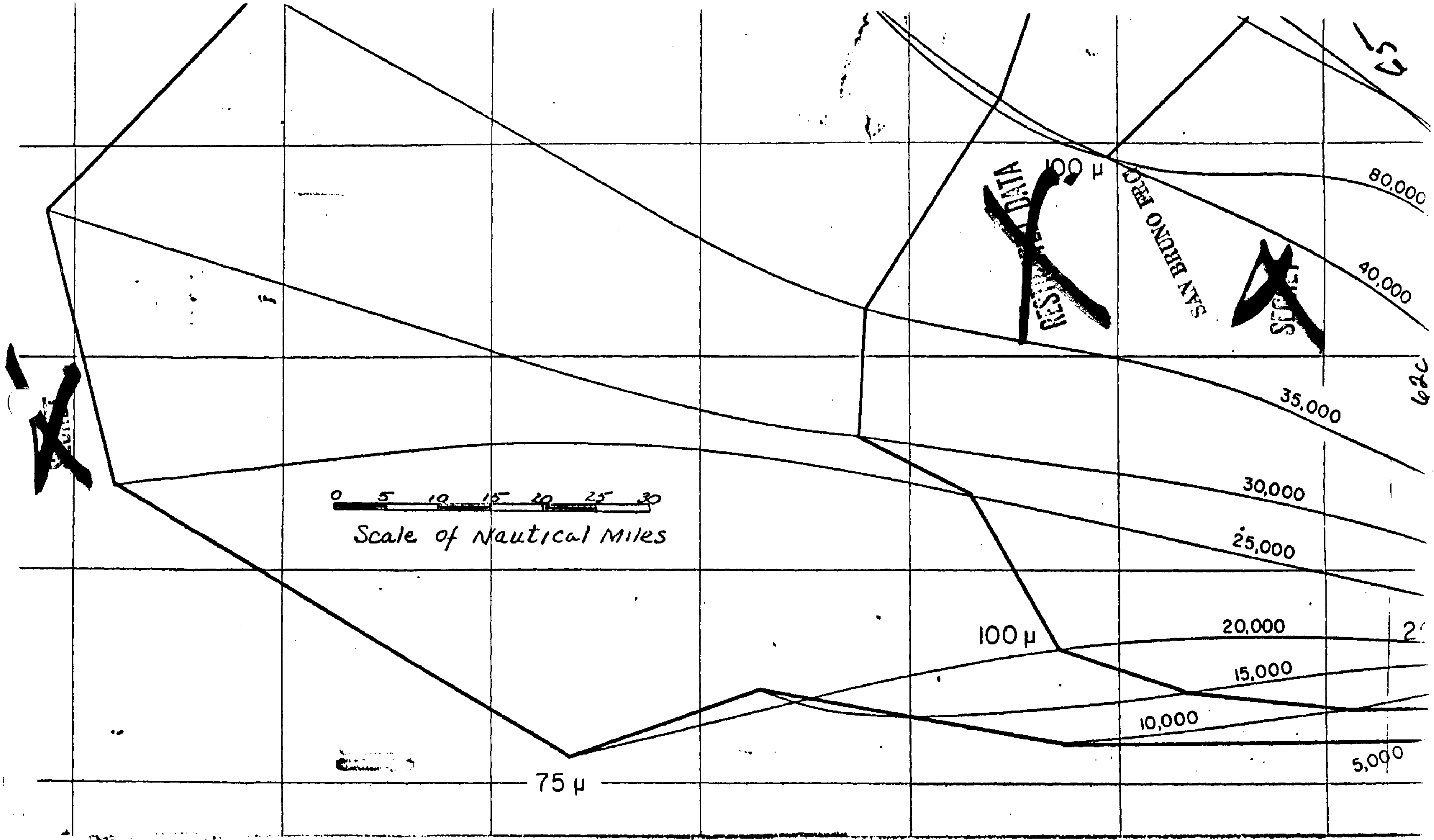
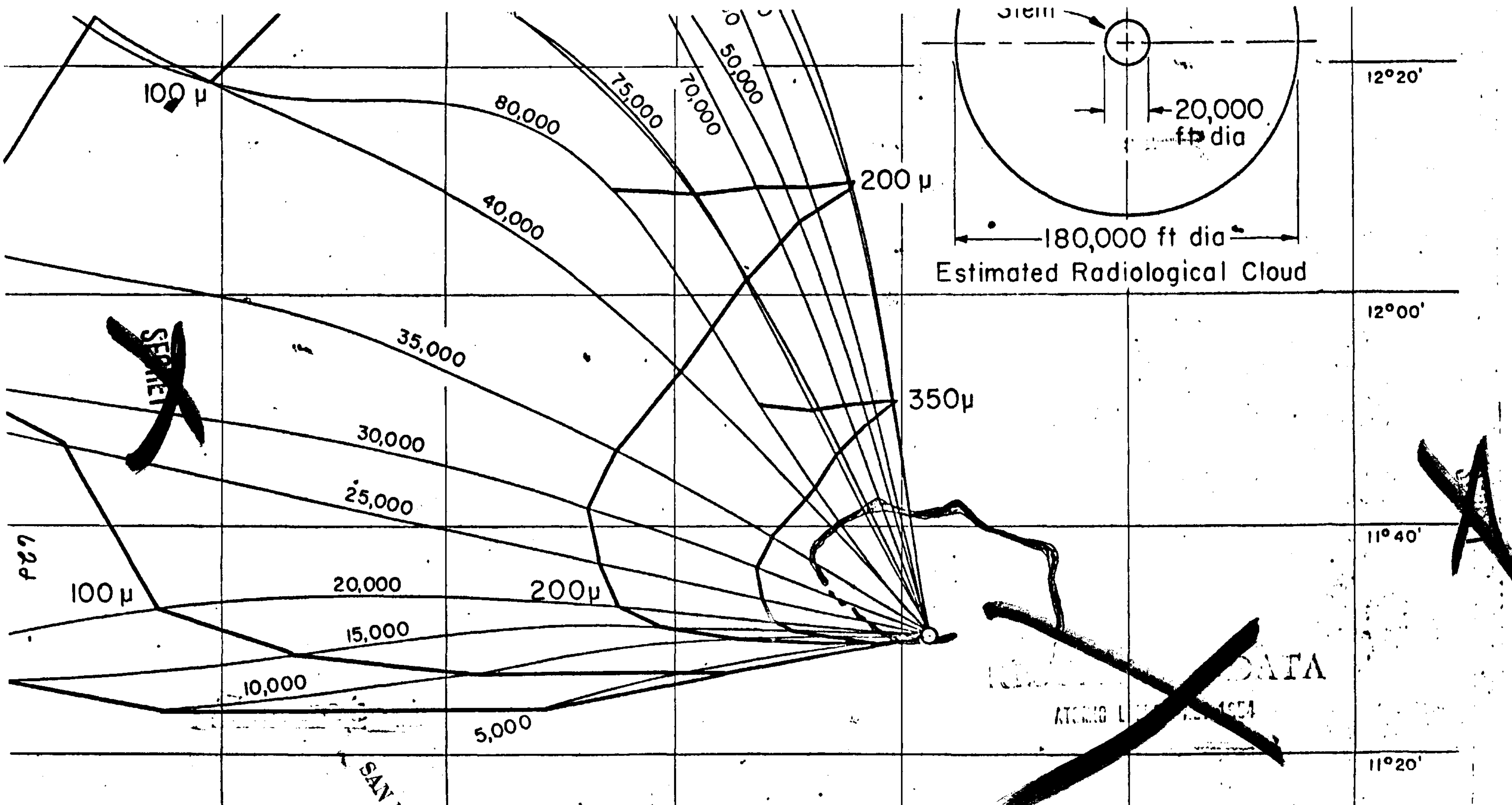
TOP


163°40'
164°00'
164°20'
164°40'
75,000
50,000
45,000
SAN BRUNO FRG
100 μ
626


0 5 10 15 20 25 30
Scale of Nautical Miles
75 μ
100 μ
100 μ
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
80,000
SAN BRUNO PRO

62c

65


Stem
20,000 ft dia
180,000 ft dia
Estimated Radiological Cloud
12°20'
12°00'
11°40'
11°20'
200 μ
350μ
200μ
100 μ
100 μ
80,000
75,000
70,000
50,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
SECRET
DATA

Any correlation of this plot and the actual fallout pattern must take into consideration the large horizontal dimensions of the initial cloud. Namely, a particular point on the ground may receive material not only from the particular size-height numbers associated with that point but from all such number pairs which fall within a cloud radius of that point. For reference, the estimated cloud and stem diameters are given as an insert to Figure 3.6.

One other effect can also influence the fallout pattern and is not easily predictable. The effective size of a particle can change as it falls.1/ This change is usually effected as condensation or evaporation of water and can manifest itself in one case as a concentrated radioactive region from local rain-out of material which would normally have been distributed over a large area.

3.1.1.4. Characterization of Fallout Material. The following general conclusions were drawn from the preliminary fallout analysis of Project 2.65:

(a) Two types of particles appeared at Site Bravo; a white irregular coral particle and an almost perfect sphere, the former being most abundant. The coral particle consisted of $CaCO_3$ with some CaO and $Ca(OH)_2$, and the spheres were mostly CaO or $Ca(OH)_2$ with a surface coating of $CaCO_3$.

(b) Radioactivity was distributed throughout the volume in the most active particles and only a few large particles showed a surface deposit of active material. The average activity per particle for the spheres was roughly ten times as great as for the coral particles.

1/ In this treatment the word "particle" is assumed to include droplets.

(c) The most abundant particle size at the size at the various stations were as presented in Table 3.1.

TABLE 3.1 PROJECT 2.65 PARTICLE SIZE AND PERCENT OF TOTAL sample ACTIVITY

Station	Particle Size (microns)	Percent of Total sample Activity
Bravo	210-420	12
	420-840	54
	840	19
Charlie	44-74	16
	210-420	25
	420-840	24
	840	10
Yoke	44-74	10
	210-420	12
	420-840	42
	840	15
YAG 40	44-74	12
	74-105	16
	105-149	14
	149-210	36
	210-420	15

Note: Only fractions contributing 10 percent or more of the activity have been included in this table.

(d) The apparent capture to fission ratio as derived by measuring the N_p^{239} and M_o^{99} activities varied markedly from sample to sample. The liquid samples were deficient in N_p^{239} by a factor of 10-100 as compared with the solid samples. The apprent capture to fission ratio varied for different particle size fractions between 0.44 and 1.54 for the Site Bravo sample and between 0.66 and 1.52 for the YAG 40 sample. The same analysis performed on a cloud sample provided by UCRL yielded a ratio of only 0.121. The ratio reported by UCRL for the cloud samples was 0.36.

At present it is not possible to evaluate the cause of these variations.

The Project 2.63 laboratory aboard the YAG 40 studied some individual particles and arrived at the following preliminary conclusions:

(a) The fallout material was very similar to that resulting from the Bravo shot at Operation CASTLE. The most predominant particle types were solid, irregular chunks and snowflake type of agglomerates. A very few white spherical particles were also present. The material appeared to consist of $Ca(OH)_2$ for the most part.

(b) On the basis of very preliminary data, the agglomerates appeared to be more active than the chunks.

(c) More detailed information was not available until the continental laboratory analyses were complete. **BEST AVAILABLE COPY**

3.1.1.5 Land Equivalent Distribution of Fallout Material. The results of the surveys of the fallout area have been represented conventionally as the land equivalent exposure rate readings at a 3 foot height at H+1 hour. In other words, the distribution of activity is measured by specifying the exposure rate that would be observed by a detector at a height of 3 feet above an infinite plane upon which the material has fallen and remained in place. This reading is extrapolated by a decay curve back to H+1 hour, even though, in all likelihood, the fallout material had not arrived at its surface location at this early time. In any case, such a plot is a representation of the surface density of active material, differing from a plot of curies per unit area by a factor which depends on the gamma ray energy spectrum.

Subject to the measurement of accurate decay curves for ~~fission-fusion~~ -

~~fission-fusion~~ resulting from a fission-fusion-fission process fallout material, a $t^{-1.0}$ relationship has been assumed for exposure rate readings from land surface distribution of fallout. Such a decay curve represents the fission product $t^{-1.2}$ decay plus an increasing relative contribution from Np^{239}. It is therefore expected to be reasonably accurate for the first 4 to 6 days until the Np^{239} relative contribution again decreases and a greater negative exponent becomes appropriate.

Exposure rate readings in and above contaminated water are doubly sensitive to changes in the gamma energy spectrum through its influence on the effective source as well as on the spectrum at the measuring device. For this reason the decay exponent that was applied to the water readings was that measured in the decay tank aboard the M/V Horizon. For the Shot Zuni fallout this was measured to be ~~1.65~~ 1.13.

The data for the fallout radiation plot in Figure 3.7 have been secured from the following sources: **BEST AVAILABLE COPY**

(a) Project 2.65 helicopter-probe aerial survey: This survey directly measured the exposure rate at a position 3 feet above the ground of some of the atoll islands. The readings for successive days' surveys were extrapolated to H+1 hour and averaged.

(b) RadSafe surveys: The RadSafe aerial readings were reduced to 3 foot readings using calculated height conversion coefficients (see Appendix C) and an additional factor of 1.5. This factor has been found necessary to normalize the readings to those taken with the project 2.65 survey. The 2.65 instrument actually made measurements at 3 feet and had been well calibrated before and after use. The conversion factor is probably due to the geometry of the RadSafe detector unit in its

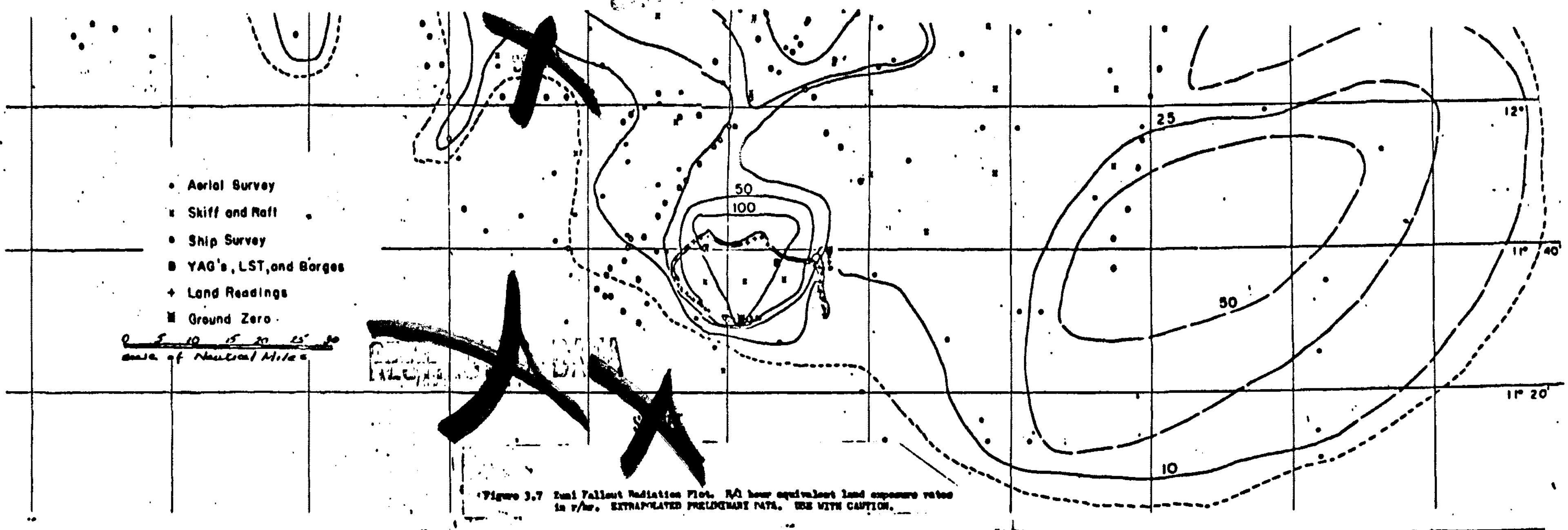
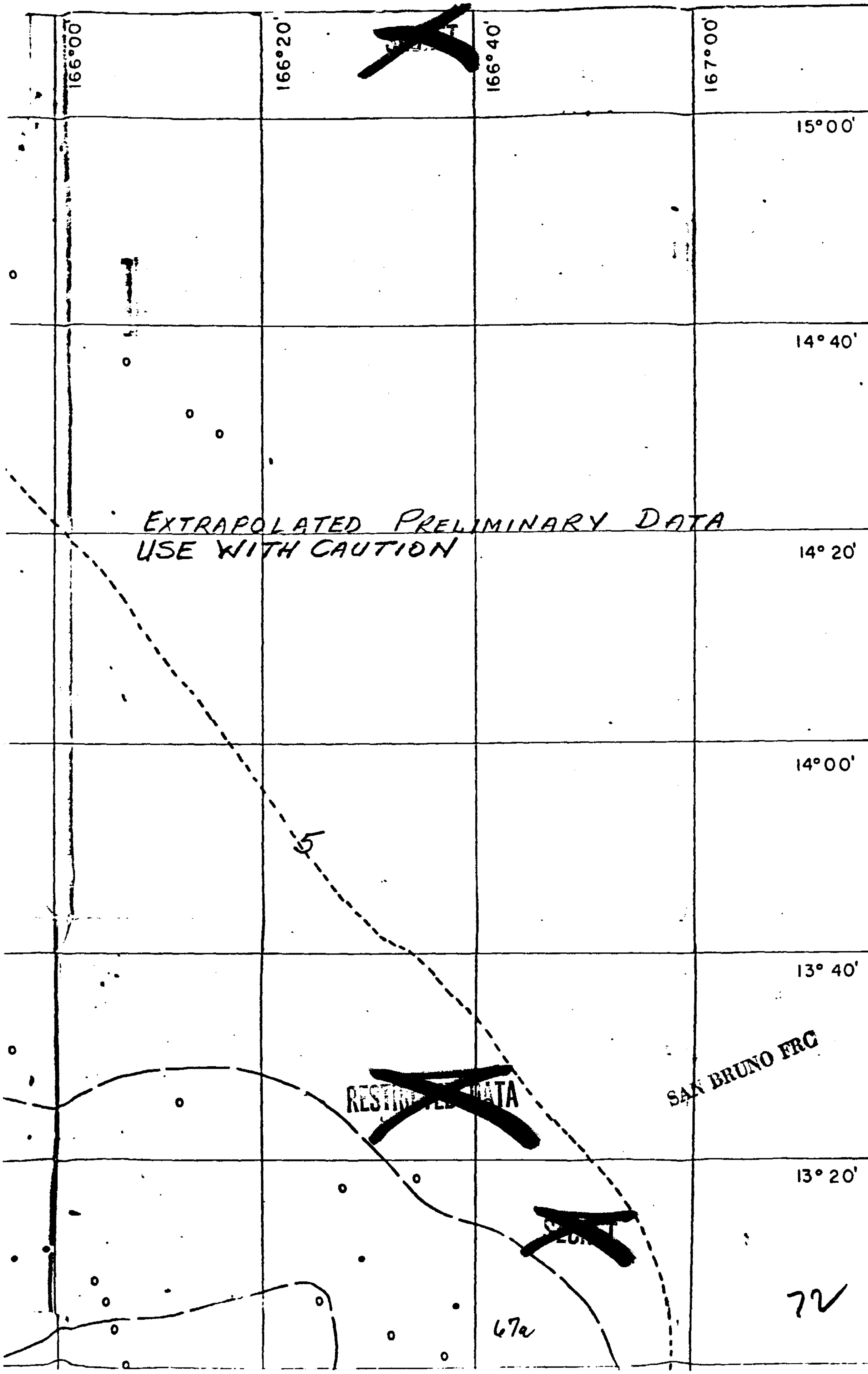


Figure 3.7 Zuni Fallout Radiation Plot. H/1 hour equivalent land exposure rates in r/hr. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.


166°00'
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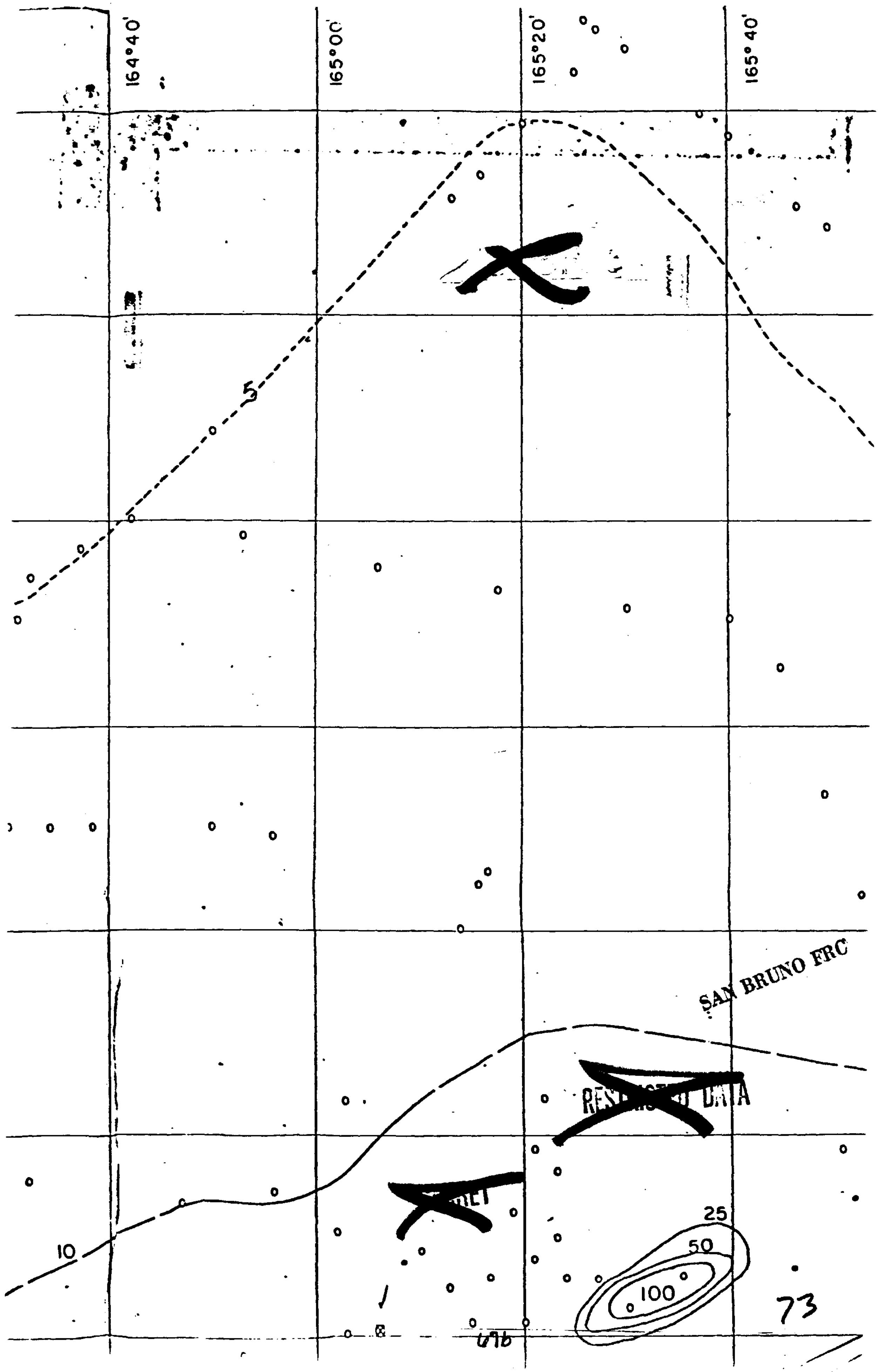
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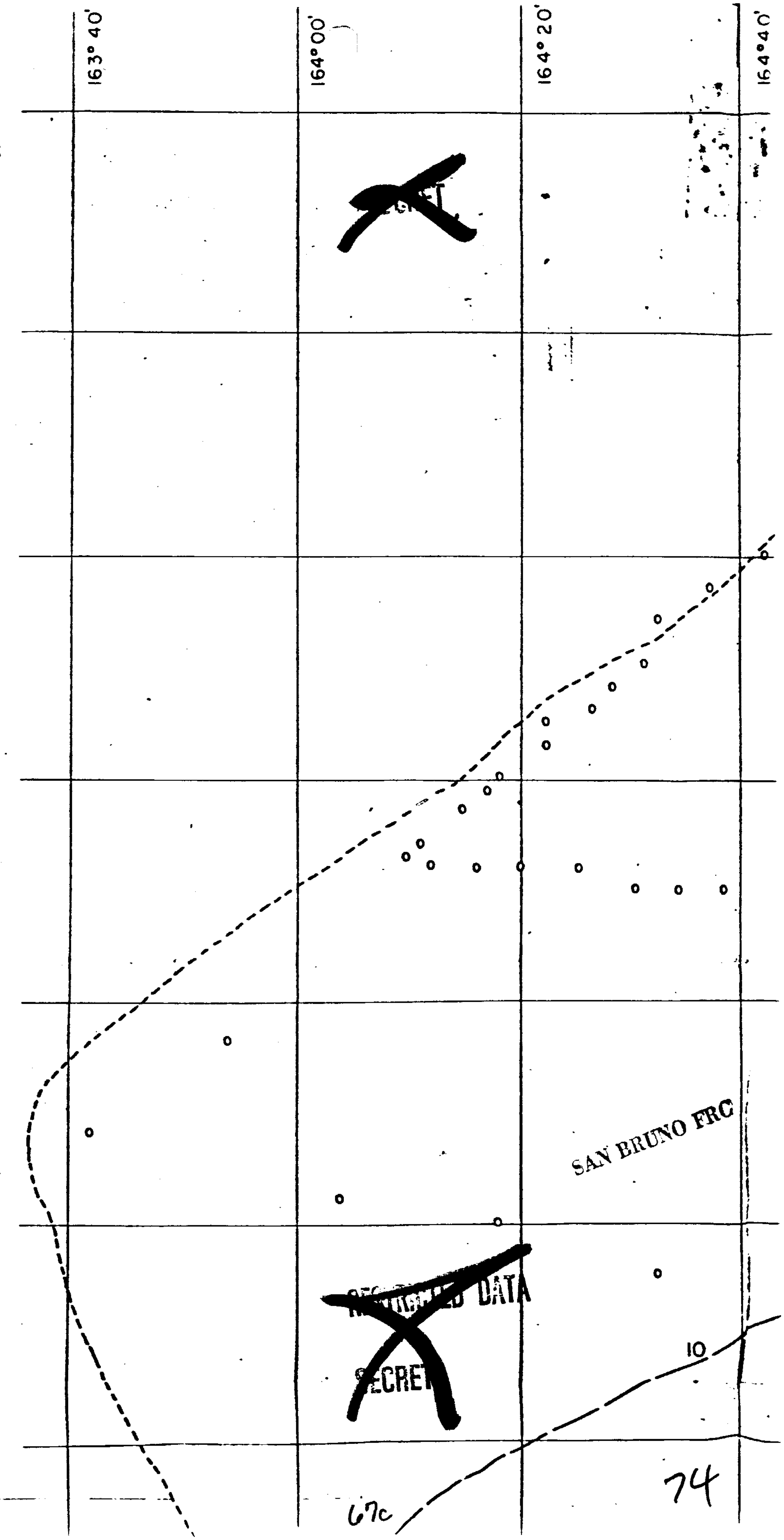
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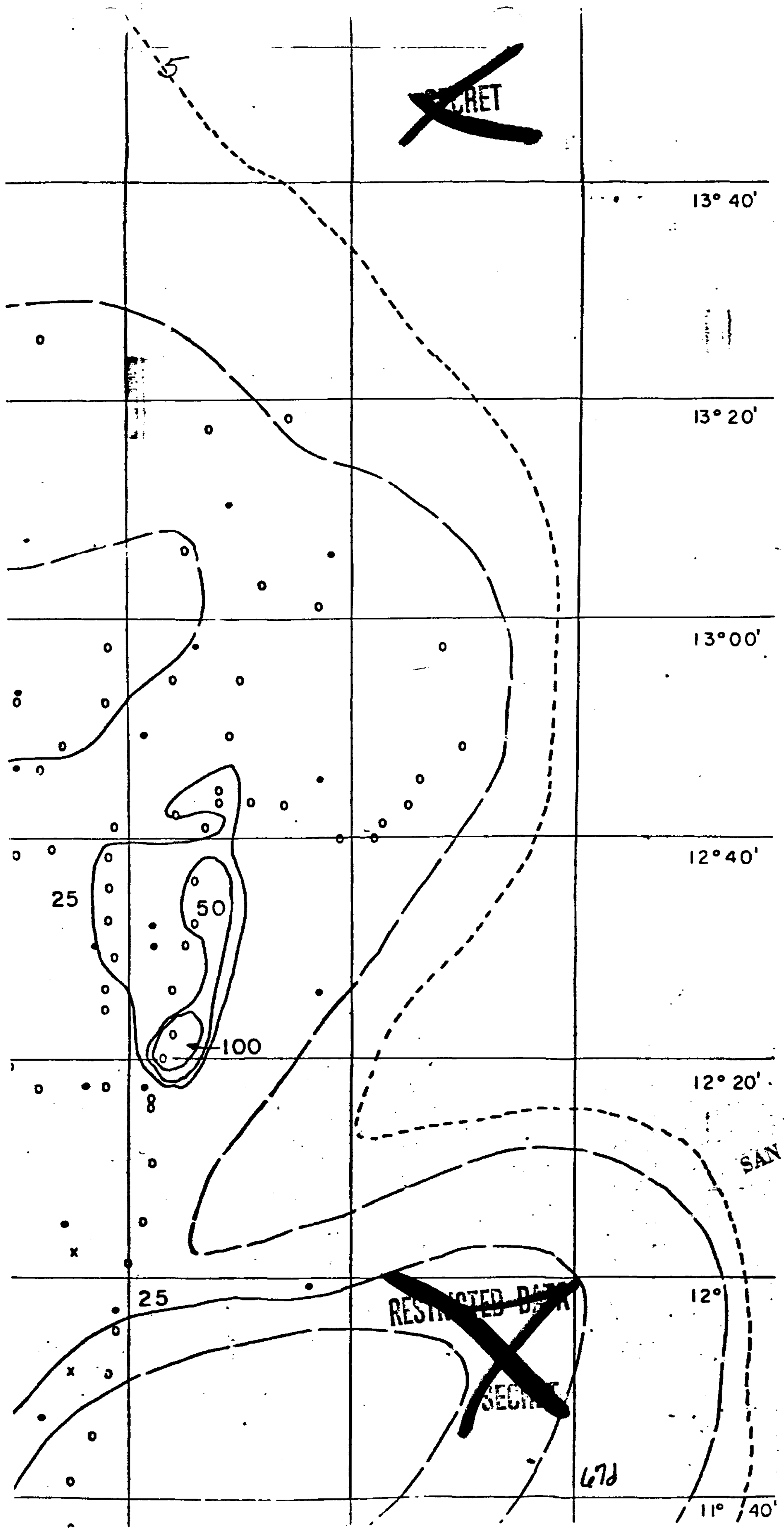

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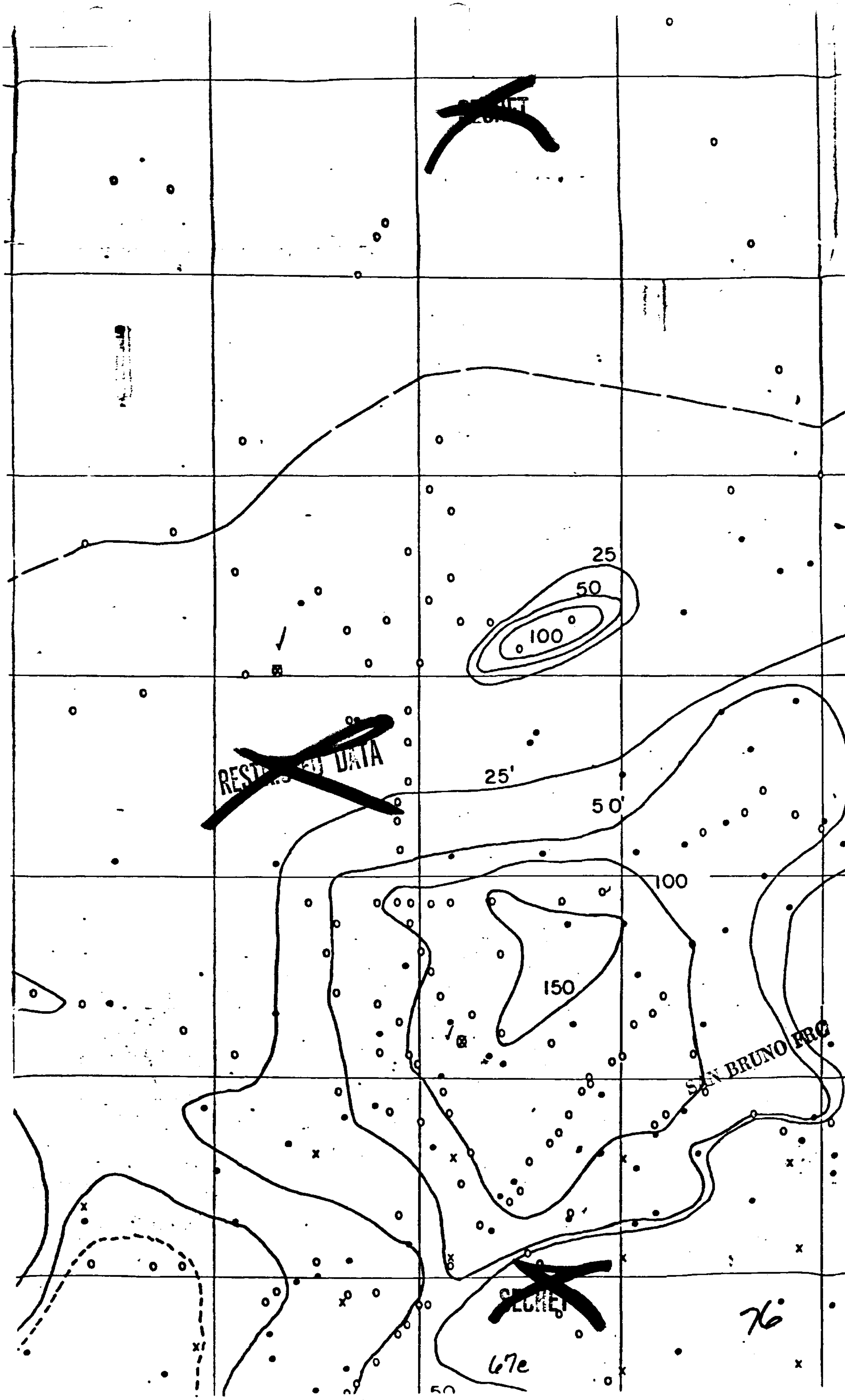
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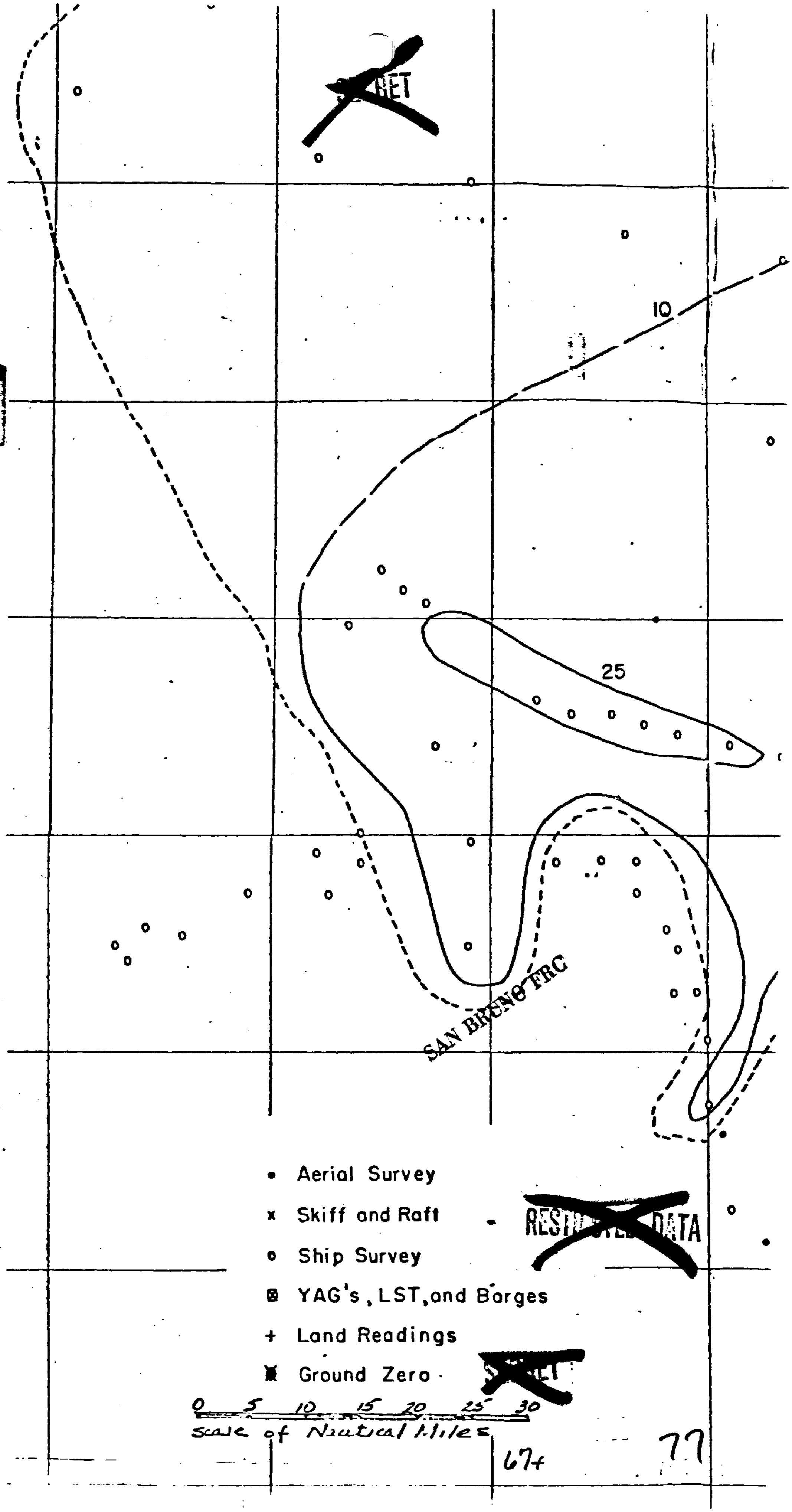
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• Aerial Survey
x Skiff and Raft
o Ship Survey
YAG's, LST, and Barges
+ Land Readings
Ground Zero
0 5 10 15 20 25 30
Scale of Nautical Miles
67+

attachment to the helicopter. Other readings on islands were also available from recovery party monitors.

(c) The Project 2.63 standard geometry monitor readings on the bottles collecting the total fallout on the pontoon raft, skiff, and island stations were used to determine the relative ground readings at these locations. The readings were normalized to the infinite land exposure rate by using the measured 3 feet exposure rate at Sites George and William together with the bottle monitor reading from the station there. This procedure is subject to some errors due to the possible variation in the collection efficiency with position in the fallout zone. For example, the funnel type collectors are more likely to retain large particulate than a fine aerosol and hence are likely to be more efficient at the stations nearer the shot point.

(d) The YAG 39 and YAG 40 "time-intensity recorder" on the forward deck provided exposure rate readings which approximate the land equivalent reading, although they were affected by the efficiency of the deck as a collecting surface. In general, these readings were found to be low compared to measurements in the ocean water and monitor readings of total collector samples.

(e) The ~~standard geometry~~ monitor readings taken under conditions of standard geometry of the Project 2.63 open-close collector trays and the total collector trays also furnished relative readings at the following locations: North Site How, YFNB barges, YAG 39, YAG 40, and the LST 611. These readings were normalized using the reading of the ocean water at the YAG 40 position. Again these readings are subject to error from a varying fallout collection efficiency.

(f) The Two YAG's, the Project 2.62 DE's, and the M/V Horizon performed measurements of exposure rate as a function of depth in the water. These readings give a direct estimate of the total activity present in a vertical column of water and hence of the equivalent land rate. These exposure rate versus depth profiles were also intended to provide an average depth of mixing so that the more numerous surface readings could also be used to compute land equivalent exposure rates. However, since the Zuni shot was detonated on land, much of the activity was associated with sizeable solid particles and only part of the activity remained in the upper few hundred meters accessible to the probe. Thus, these readings are subject to relatively large errors. BEST AVAILABLE COPY

(g) The numerous surface exposure rate readings measured by the survey vessels and the YAG's can be reduced to equivalent land radiation readings if the effective depth of mixing of the radioactive water is known. The preliminary reduction of the radiation depth profile data indicated that the depth of penetration was about 54 meters at H/10 hours, increased linearly to 90 meters at H/30 hours, and remained constant after this time. The data from the surface readings were therefore reduced using these depths of penetration at all positions in the fallout pattern. Neglecting space variations in the depth of penetration can produce some errors, particularly close in, because the larger sized particulate in the fallout which arrives nearer to the shot point is likely to penetrate more rapidly under the influence of gravity than would be expected from the water mixing rate. Therefore, the effective depth of mixing could easily be much greater near ground zero than in the more remote regions of the fallout pattern where smaller particulate is responsible for the activity.

In order to calculate ...

The factor ~~used~~ to reduce the reading under the surface of the water it is necessary to assume that the activity in the water is ... to the equivalent land rate ~~was~~, 10 X d, where d is the depth of mixing. ... the result that factor is ... This factor can be derived as follows: the activity present in a vertical column of 1 m² cross section and volume "d" m³ of water is to be placed on one m² of ~~surface~~ the plane, and a density of 1 curie/m³ in water produces one tenth of the exposure rate ~~as~~ existing at 3 ft. above a surface distribution of 1 curie/m². (See Appendix C.) ... placed on a plane and the exposure rate measured 3 ft above the plane.

A rough correction was made in the survey data for the motion of the ocean water subsequent to the deposition of the fallout. For the purposes of this preliminary report the currents were approximated by a uniform drift of 10 nautical miles per day toward 260 degrees azimuth in the region north of 12 degrees 00 minutes north latitude, a drift of 10 miles per day toward 180 degrees azimuth in the region southwest of Bikini Atoll, and a zero drift southeast of Bikini Atoll. These motion patterns were smoothly connected in intermediate regions. The motion was assumed to commence at an average time ~~of arrival~~ of H+6 hours.

(h) The Project 2.64 aerial survey readings taken at an altitude of about 300 feet were reduced to readings in the water by multiplication by a factor of 10. This factor included a factor of 3.3 for the finite acceptance angle of the detector, 1.5 for the effective air attenuation between the water surface and 300 feet, and 2 to convert the reading over the water into a reading inside the water (see Appendix C). Using the same normalization factor computed for the Project 2.62 water readings, these numbers were reduced to equivalent land exposure rates.

3.1.1.6 Central Time of Arrival Contours. The contours in Figure 3.8 represent the calculated times at which a particle originating directly

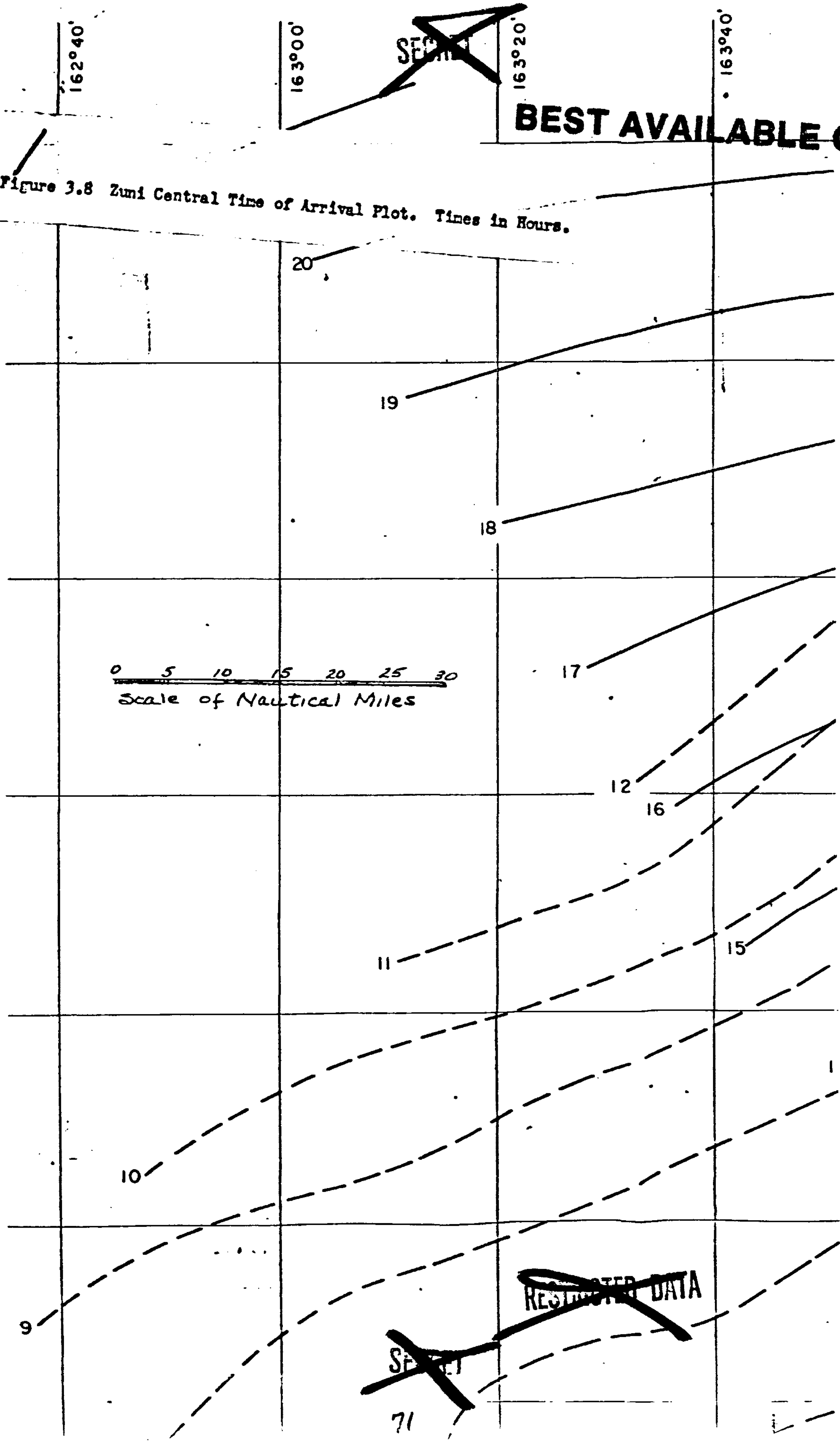
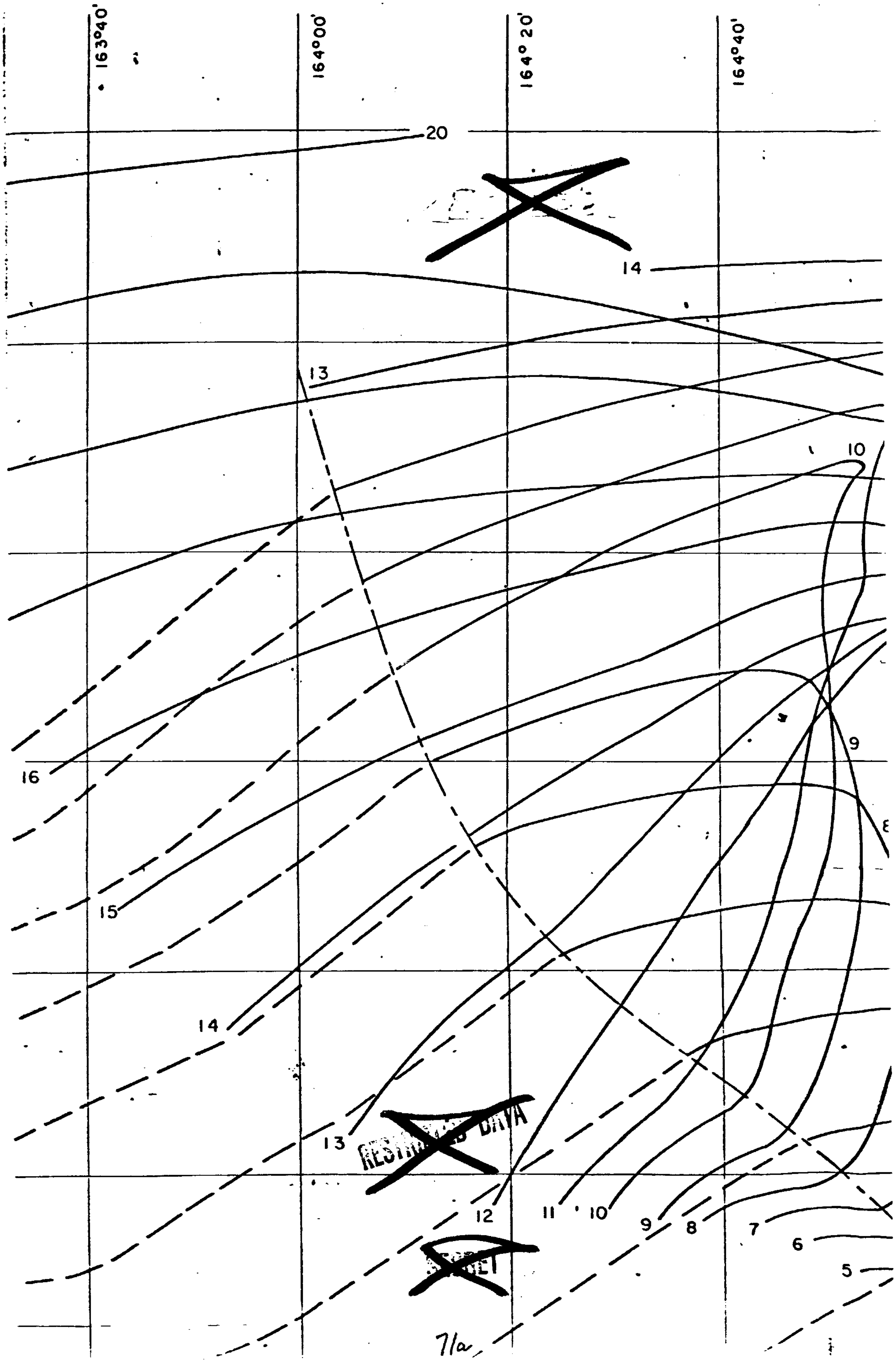


Figure 3.8 Zuni Central Time of Arrival Plot. Times in Hours.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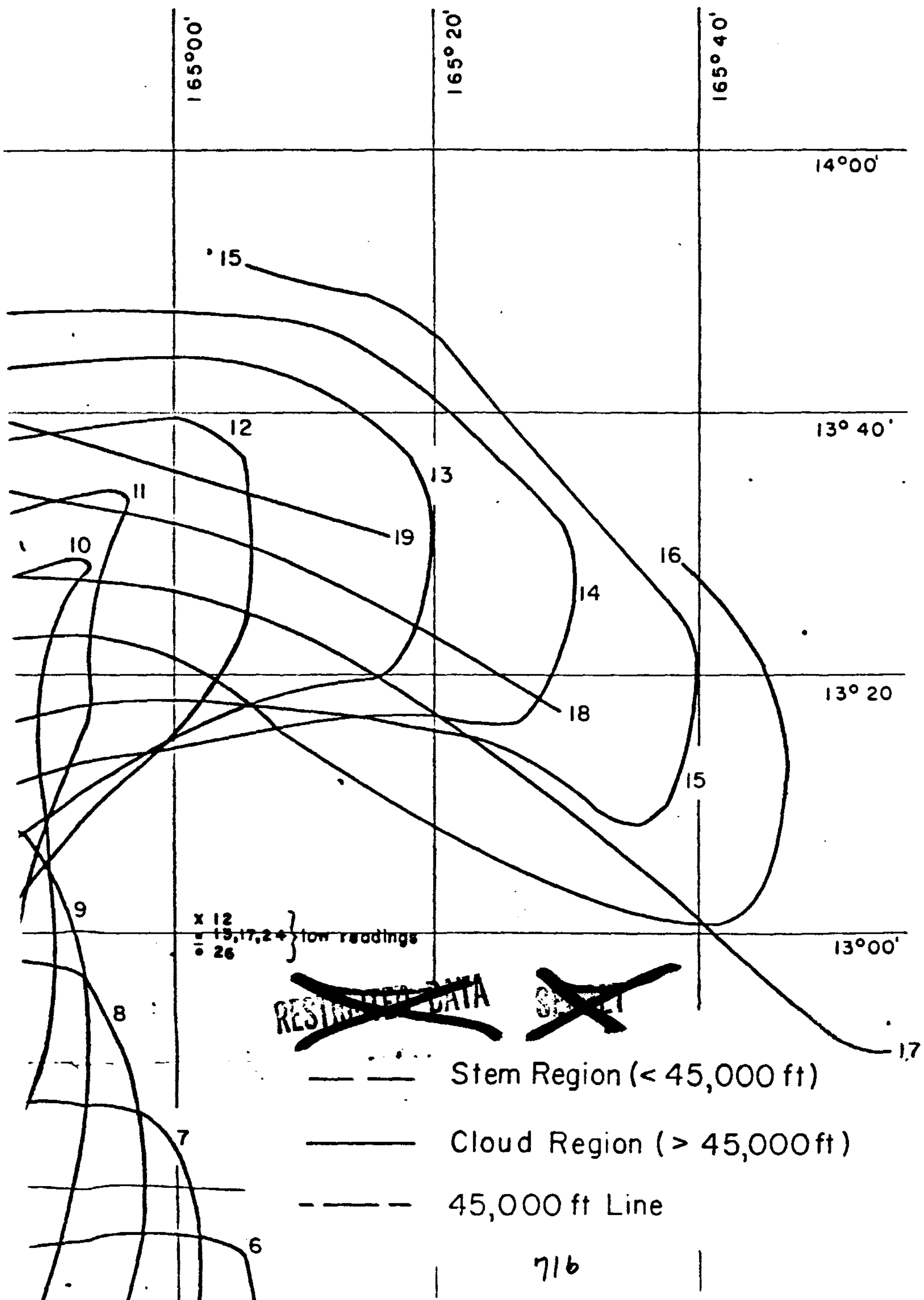

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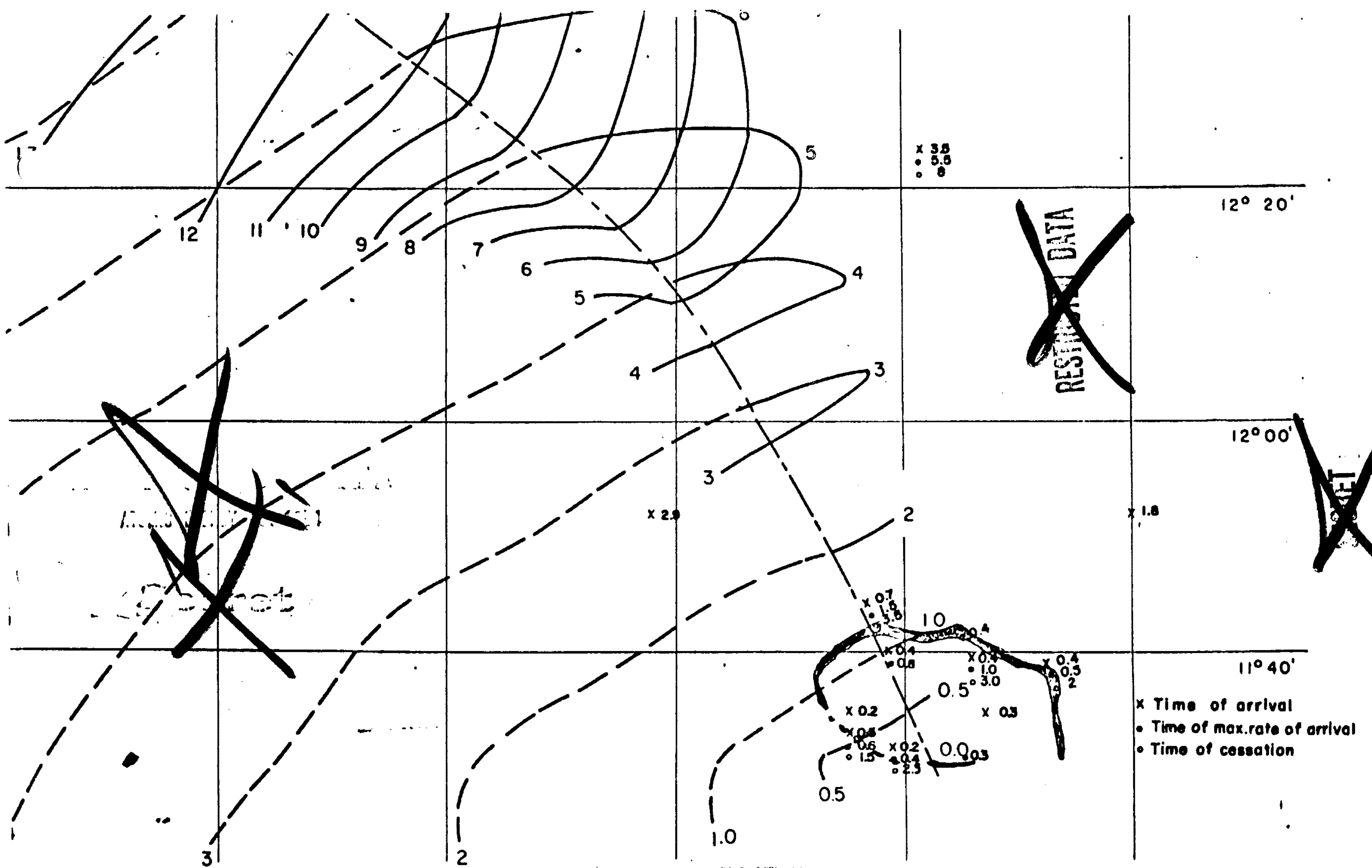
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• 0.8
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x 0.5
x 0.3
x 0.2
• 0.4
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∘ 1.5
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x Time of arrival
• Time of max.rate of arrival
∘ Time of cessation

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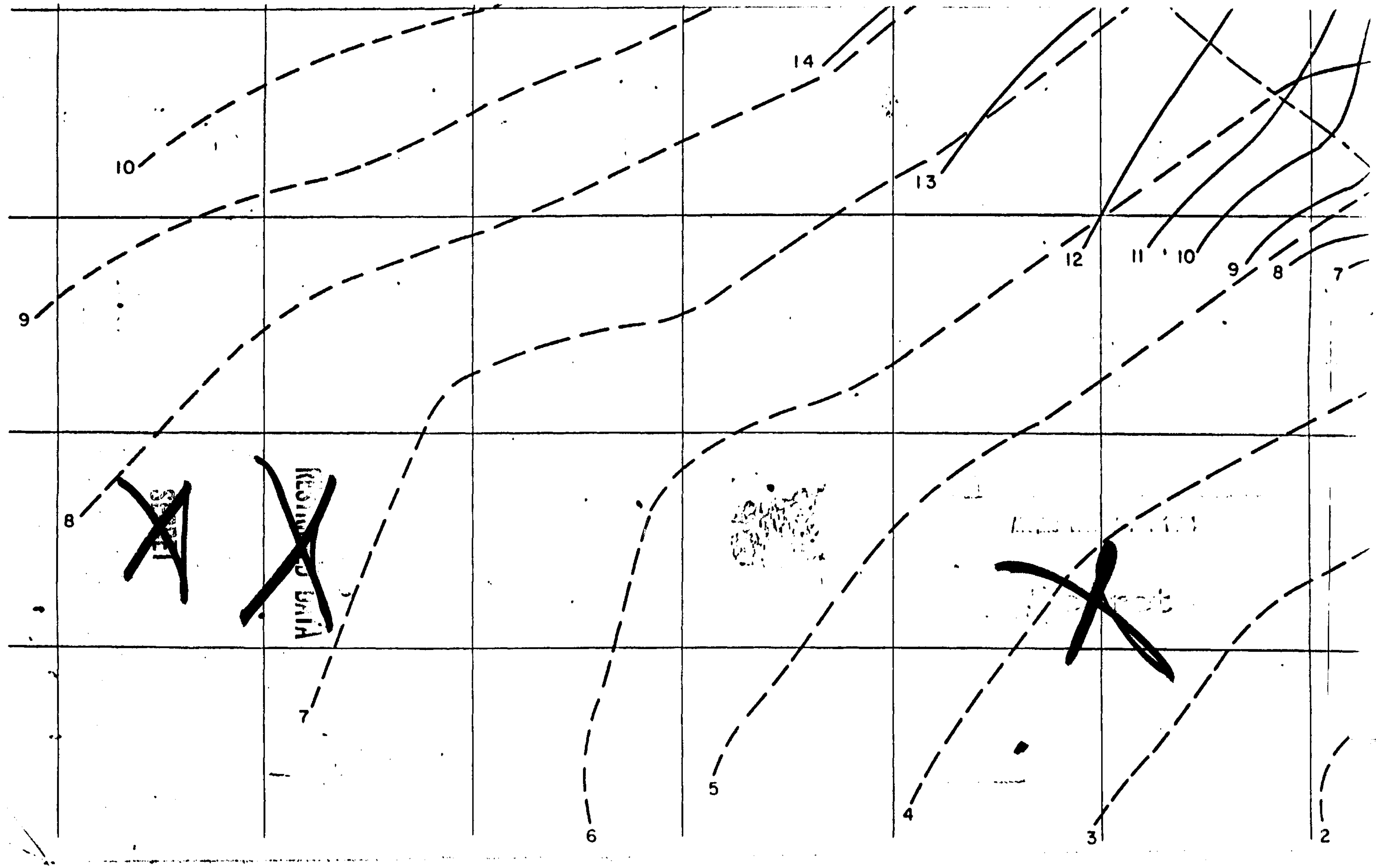
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above surface zero would arrive at a location on the surface. The fact that contours are exhibited which indicate two fallout times associated with some points results from the possibility that particles from two regions in the initial cloud can arrive at the point. Since the initial cloud is not a vertical line source but has appreciable horizontal extent, the actual time of arrival at a point corresponds to the minimum central time of arrival computed with all locations enclosed by a circle of cloud radius drawn about that point. ~~for all points within a cloud radius.~~ Likewise, the time of cessation corresponds to the maximum central time of arrival for all locations ~~points~~ within ~~a cloud radius~~ that circle.

Figure 3.8 also presents the observed time of arrival, time of peak rate of arrival of activity, and time of cessation of fallout observed for the Zuni event. The data is gathered from the following sources:

(a) Time of arrival detectors on the skiffs and pontoon rafts.

(b) Gamma "time-intensity recorders" aboard YAG 39, YAG 40, LST 611, YFNB 13, YFNB 29, and the Site How station of Project 2.63.

(c) Monitor of trays of incremental samplers located aboard ships by Project 2.63 and on islands by Project 2.65.

~~(d) The gamma exposure rate recorders installed at some land stations by Project 2.2.~~

3.1.1.7 Ten Hour Exposure Contours. For applications to practical military situations, the H+1 hour land equivalent exposure rate is not particularly appropriate. The times of arrival of the fallout may vary greatly along a particular radiation contour and hence the total dosage to personnel in those areas will vary. Figure 3.9 presents contours of the total exposure received at locations in the fallout zone from the

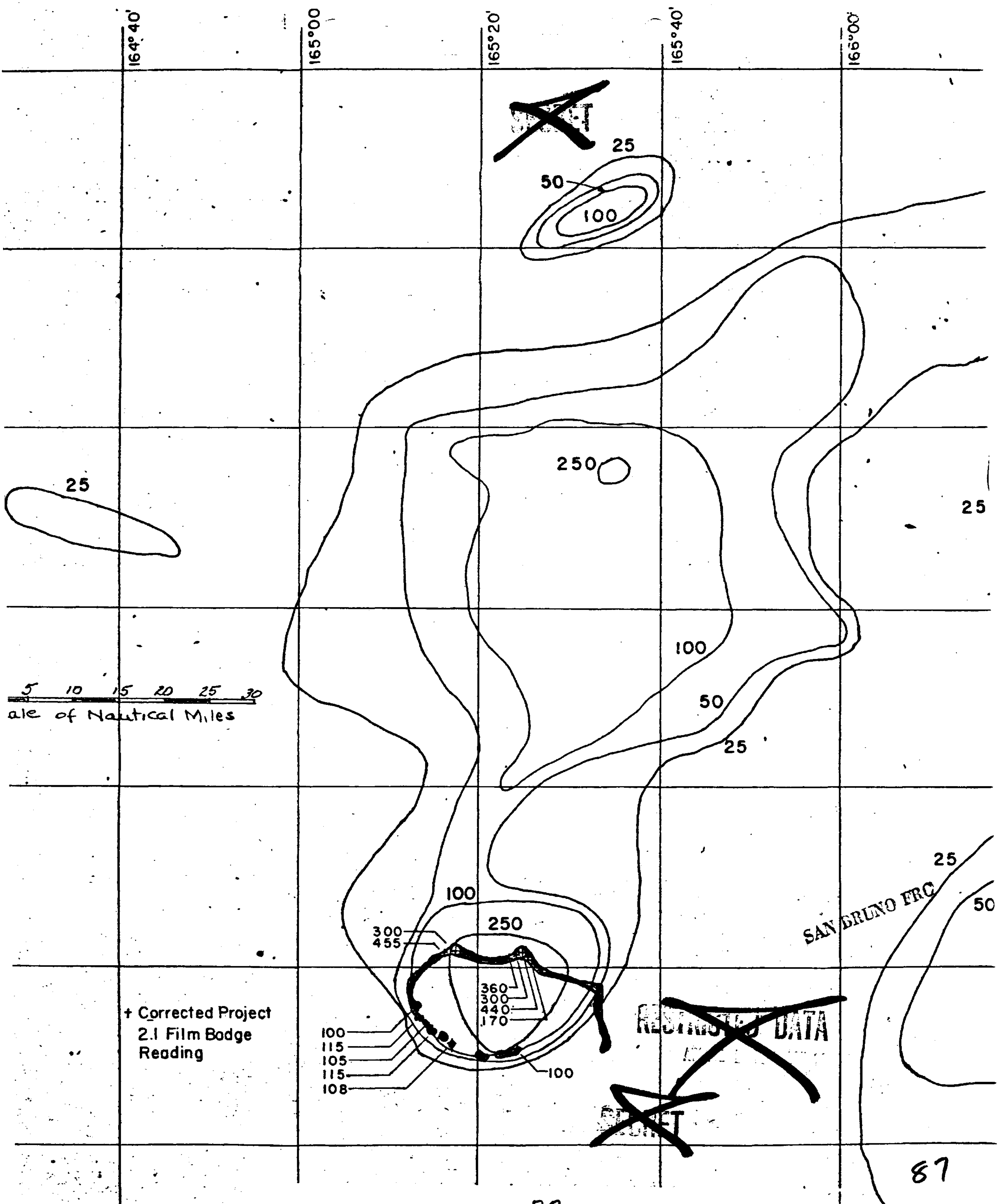

Figure 3.9 Zuni Ten Hour Exposure Contours. Exposure in r.

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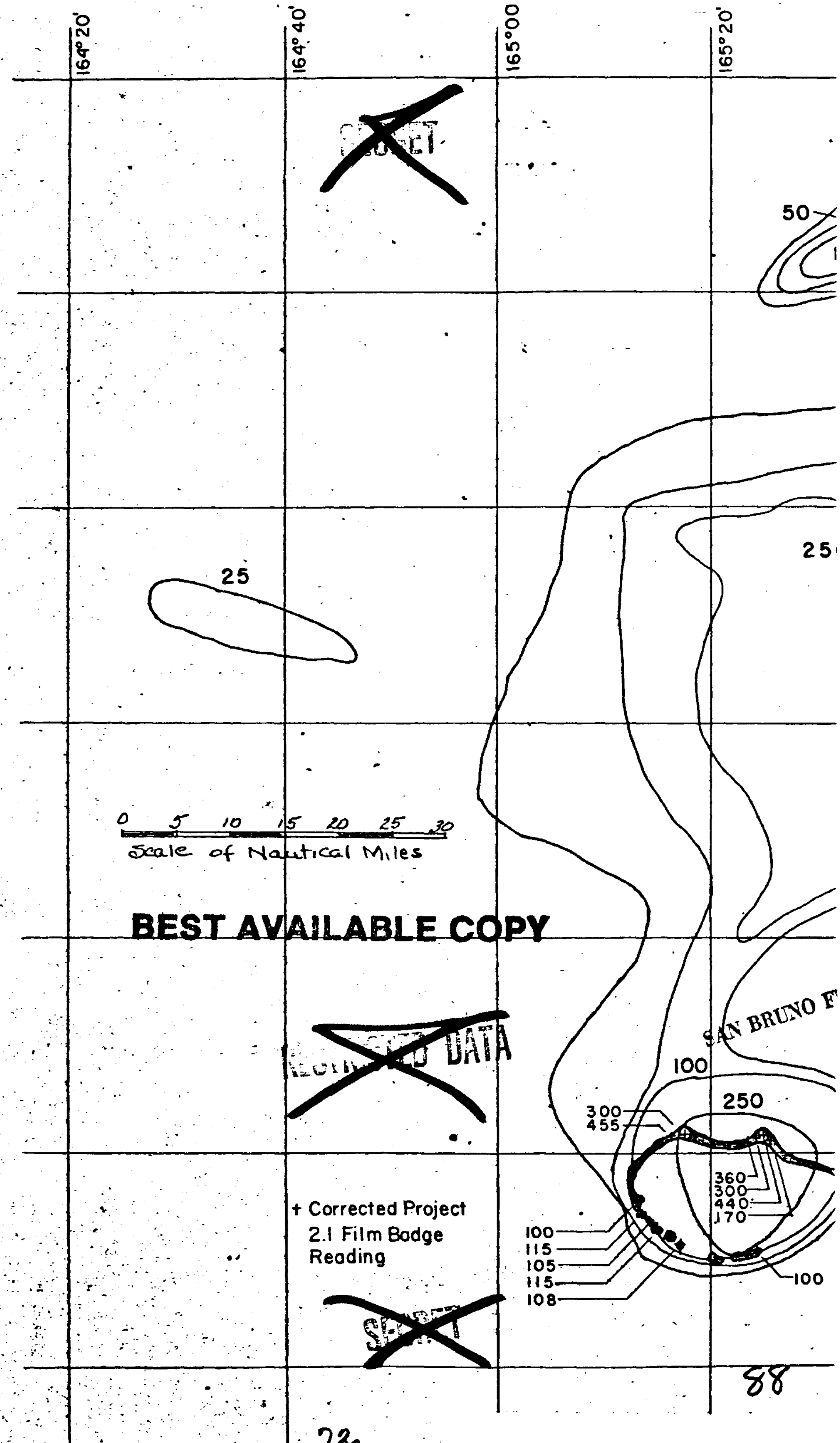

Figure 3.9 Zuni Ten Hour Exposur

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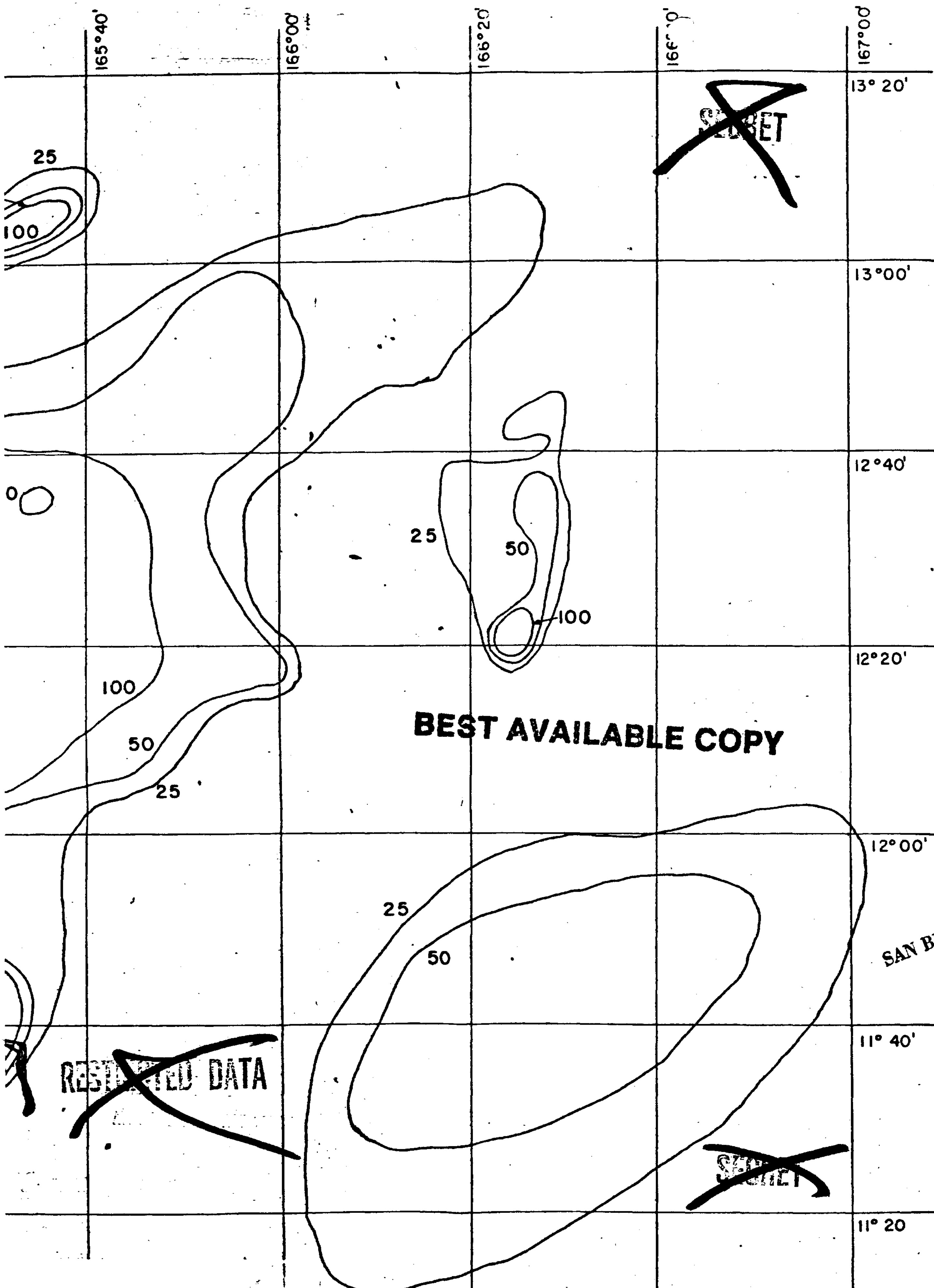

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Contours. Exposure in r.
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central time of arrival of fallout until 10 hours later. The figure has been constructed using the experimental fallout radiation distribution from Figure 3.7 and the calculated central time of arrival contours of Figure 3.8. The assumption has been made that the activity decays according to a $t^{-1.0}$ decay relationship. In interpreting this plot in terms of exposure to personnel experiencing the fallout the assumption is made that the exposure is the same as that which would have been experienced if all the material had arrived at the central time of arrival of fallout. This assumption is equivalent to an assumption of equal areas demonstrated in Figure 3.10. **BEST AVAILABLE COPY**

The total exposure data of the Project 2.1 film badges and dosimeters were corrected for the difference between recovery time and 10 hours after the central time of arrival and have been presented as data points on Figure 3.9.

3.1.1.8 Gross Decay Exponent. The decay characteristics of the fallout samples will be, in general, determined by the combination of the fission product and neutron activation product decays. The predominant capture product activity at the times the samples were observed was from Np^{239} (2.3 day half life) which occurs in abundance whenever the fission yield of the weapon results mostly from fast neutron fission of U^{238}. The assumption of a $t^{-1.0}$ decay for analysis of the Zuni fallout radiation data was chosen to represent the combination of the fission product and Np^{239} activity during the period of the surveys (D to D+4). Later, more precise analyses will undoubtedly be based on the actual observed decay.

FIG. 8

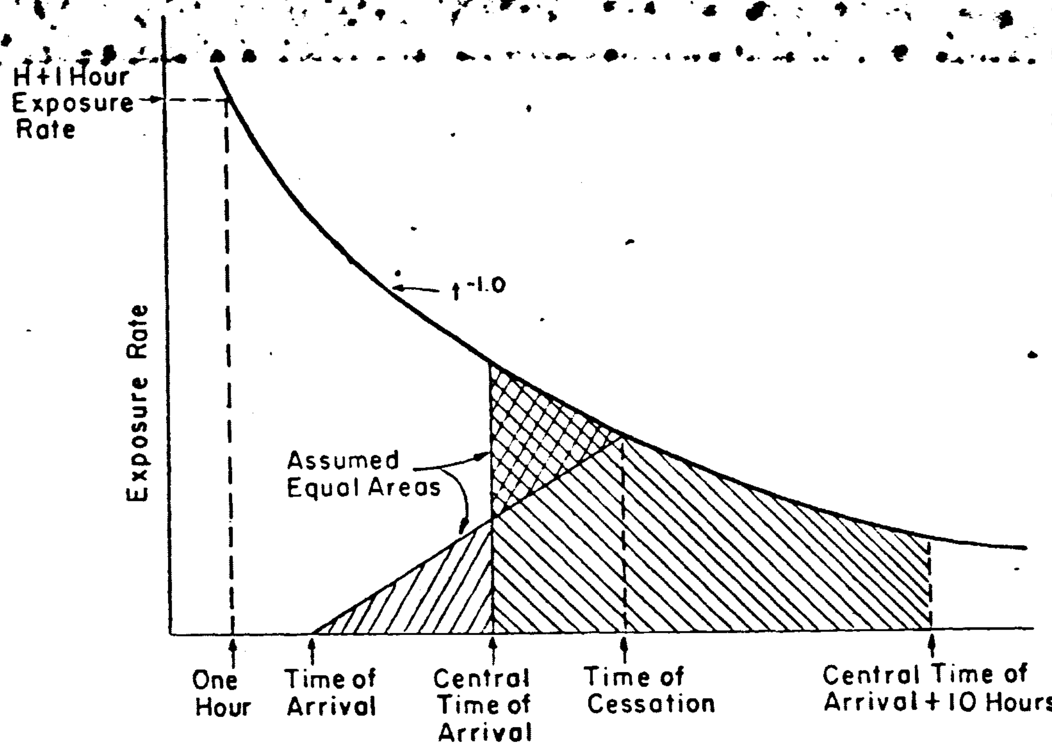

Figure 3.10 Calculation of Ten Hour Exposure Values. Ten hour exposure as used in this report is area under curve from central time of arrival to central time of arrival plus 10 hours.

The Np^{239} capture to fission ratio reported by UCRL for the Zuni event was approximately 0.36.

Preliminary observations by Projects 2.63 and 2.65 on the gamma photon decay, gamma exposure rate decay, beta disintegrations per minute decay, and the gamma exposure rate decay observed by measurements on radiation fields from contaminated islands are summarized in Table 3.2. The preliminary results from Projects 2.62 on the decay constant applicable to the gamma exposure rate measured in contaminated water has also been included in Table 3.2.

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TABLE 3.2 GROSS DECAY EXPONENTS FOR ZUNI

$$A(t_2) = A(t_1)\left(\frac{t2}{t_1}\right)^{-n}$$

	Time Range (hours)	5-20	20-50	50-200
Decay Exponent	Gamma Photons*	0.6	0.6	1.2
	Gamma Exposure Rate	0.9	0.9	1.0
	Beta dis/min#	0.6-0.9	0.7-1.4	0.8-1.0
	Field Gamma Exposure rate	-	0.9	-
	Gamma Exposure in Water	-	~~1.05~~ 1.13	-

*YAG 40 Samples only.

#Samples subject to much variation. Numbers quoted are ranges of observed decay exponents.

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3.1.2 LaCrosse.

3.1.2.1 Introduction. The LaCrosse Shot was fired on an artificial island on the reef off Site Yvonne, Eniwetok Atoll, on 5 May 1956, at 0625M. The yield of the weapon was measured to be 38.5 KT. The environment of the shot point consisted of shallow water and reef. Therefore, the burst was essentially of the land surface type. In the vicinity of the burst point was located large quantities of iron pipe used in the diagnostic instrumentation.

3.1.2.2 Particle Fall Plot. The particle fall plot illustrated in Figure 3.11 has been constructed for only the larger particle sizes, since only the atoll area fallout was documented, and hence does not need to include space or time variation of the wind structure. The other comments made in Section 3.1.1.3 about the limitations and interpretation of this plot are applicable here also.

3.1.2.3 Characterization of Fallout Material. Project 2.65 only participated on a limited basis in the fallout collection from the LaCrosse Shot. The best sample was secured from a truck canvas on Site Cone. Two types of particles were observed, one of which appeared to resemble natural white coral and the other which was partially or totally black and contained varying amounts of iron. The radioactivity appeared to be uniformly distributed throughout the volume of both types of particles. Eighty-seven percent of the activity was associated with particles in the 210-420 micron sieved size fraction (cf Figure 3.11). Project 2.65 observed indications of fractionation of Np^{239} relative to Mo^{99}. The Mo^{99} activity was assumed to measure the fission product activity and

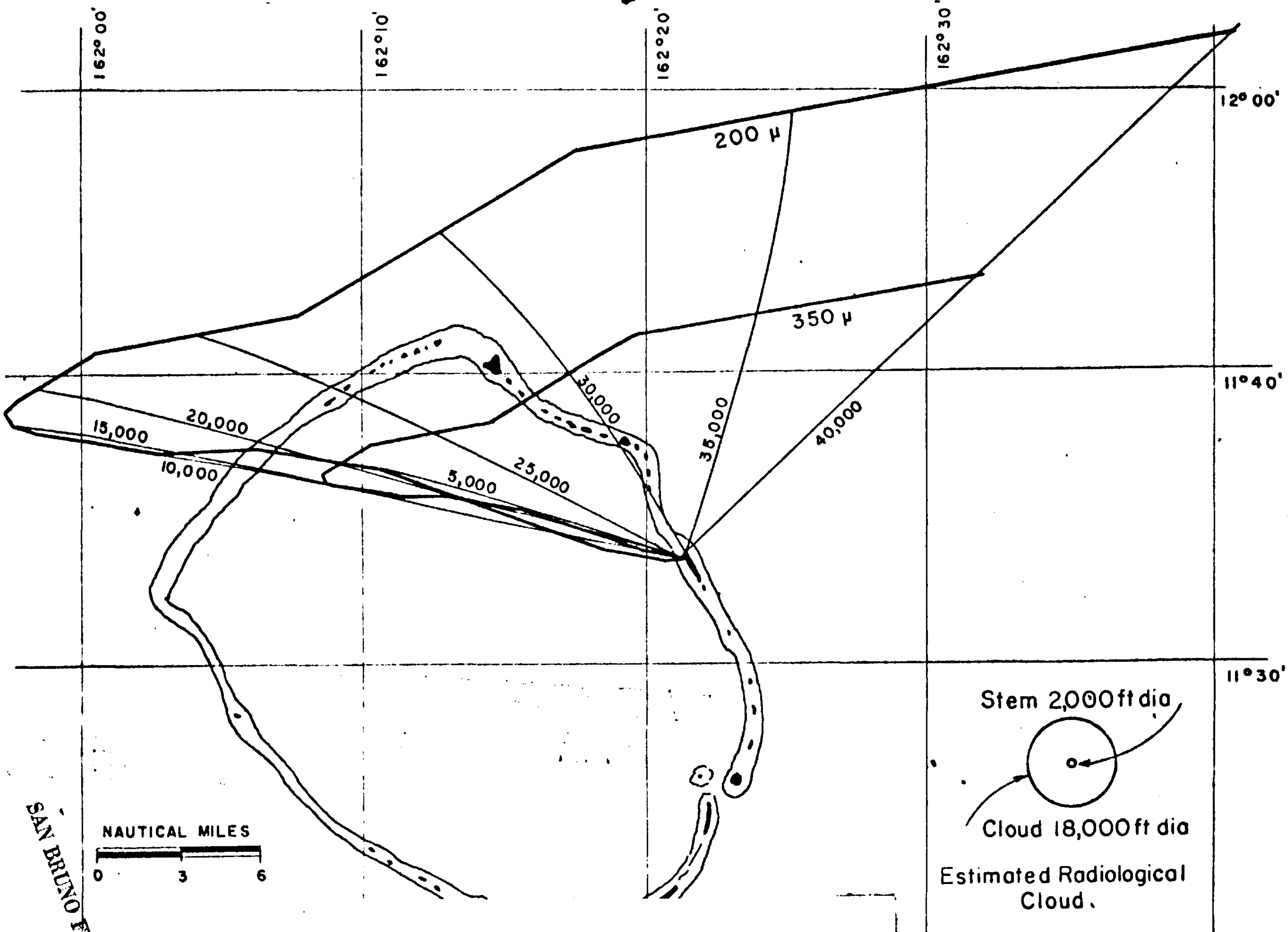

Figure 3.11 LaCrosse Particle Fall Plot.

a capture to fission ratio was calculated for each sample. The apparent ratio seemed to vary from sample to sample with possibly a decrease with increasing particle size, varying from approximately 0.28 in the smallest sizes (75 micron) to 0.20 in the largest (200 micron). These numbers are appreciably larger than those from the cloud sample analysis performed by LASL which yielded a capture to fission ratio of 0.086. Therefore, there was apparently an overabundance of Np^{239} in these samples as compared with the Mo^{99}.

3.1.2.4 Land Equivalent Distribution of Fallout. Radiation data at sites on the islands were available from two sources: The Project 2.65 helicopter-probe survey and RadSafe readings. The probe readings have been corrected to H+1 hour by using a $t^{-1.2}$ decay expression. In addition to this factor, the RadSafe readings were converted from readings at 25 feet and 50 feet altitudes to 3 feet readings by multiplying by 2.5 and 3.2 respectively. Where many readings were taken over the same island, the D-day RadSafe reading and the three successive day probe readings were averaged. In these cases the consistency of the readings was within a factor of two. The resulting radiation pattern is characterized by the data points in Figure 3.12. Unfortunately, the data do not cover enough area to allow contours to be drawn, so only a few general conclusions will be derived from this event. The radiation levels near the crater are indicated in Figure 3.13.

3.1.2.5 Central Time of Arrival Contours. Figure 3.14 presents the predicted central time of arrival contours for the LaCrosse Shot. No time of arrival detectors were operating during the fallout from this

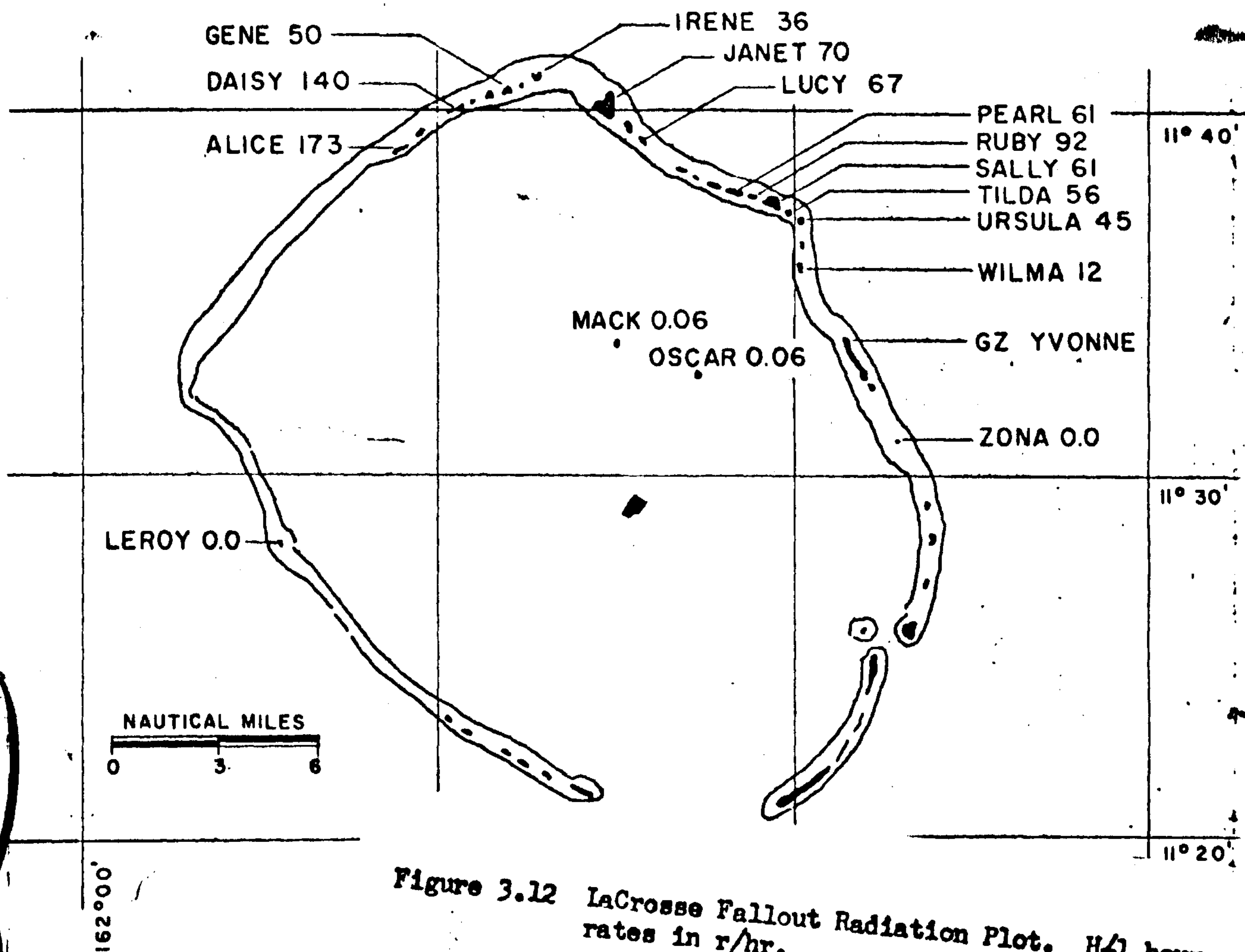

Figure 3.12 LaCrosse Fallout Radiation Plot. H+1 hour equivalent land exposure rates in r/hr.

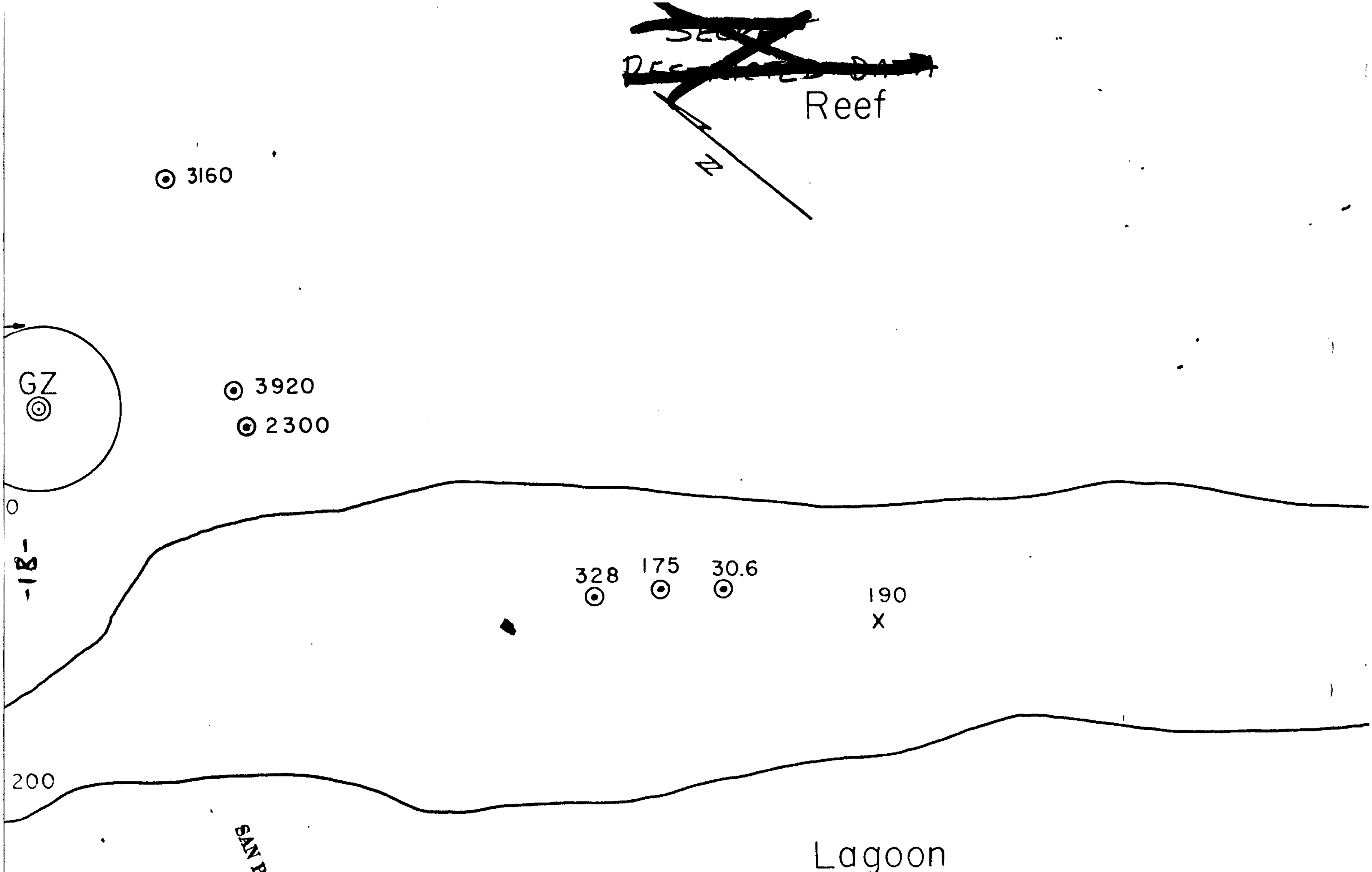

Figure 3.13 LaCrosse Exposure Rates Near Crater. Equivalent land readings on the reef and on Yvonne converted to r/hr at H+1.

[redacted]

[redacted]

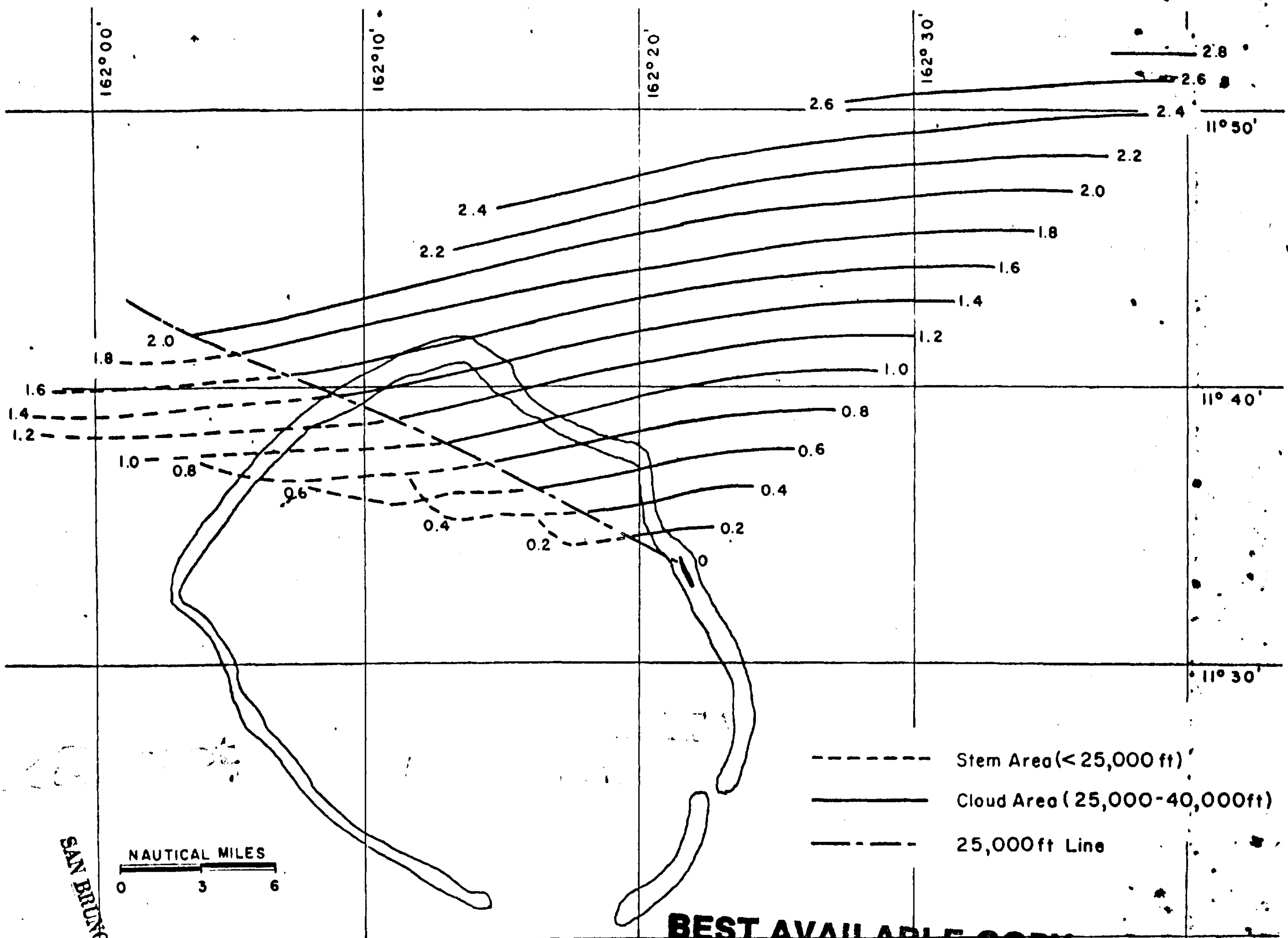

Figure 3.14 LaCrosse Central Time of Arrival Plot. Times in hours. [redacted]

event, but these contours can be used to compare total exposure measurements with exposure rate measurements, and hence are presented here for convenience only.

3.1.2.6 Cross Decay Exponent. Project 2.65 measured separately the gamma and beta decay curves of the LaCrosse fallout samples over the period from 30 hours to 530 hours. The decay exponent of the gamma exposure rate was observed to be 1.3 and of the beta intensity (counts per minute) 1.2. The gamma exposure rate readings in the field had a decay exponent of 1.4.

3.1.3 Mohawk

3.1.3.1 Introduction. The Mohawk device was detonated on a 300 foot tower at Site Ruby on 3 July 1956, at 0606M. The yield of the weapon was measured to be [redacted] of which [redacted] Since the fireball radius was greater [redacted] the local contamination produced by the Mohawk Shot should be at least [redacted] that produced by the same yield surface burst. To correct for tower height and the

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Program 2 participation in the Mohawk event was limited to the Project 2.65 helicopter probe aerial survey.

3.1.3.2 Particle Fall Plot. Since only the close-in fallout was documented, the particle fall plot has been constructed for the larger particles only and was not corrected for any space and time variations of the wind profile. Figure 3.15 represents the particle fall plot for the Mohawk Shot time winds and is, of course, subject to the limitations

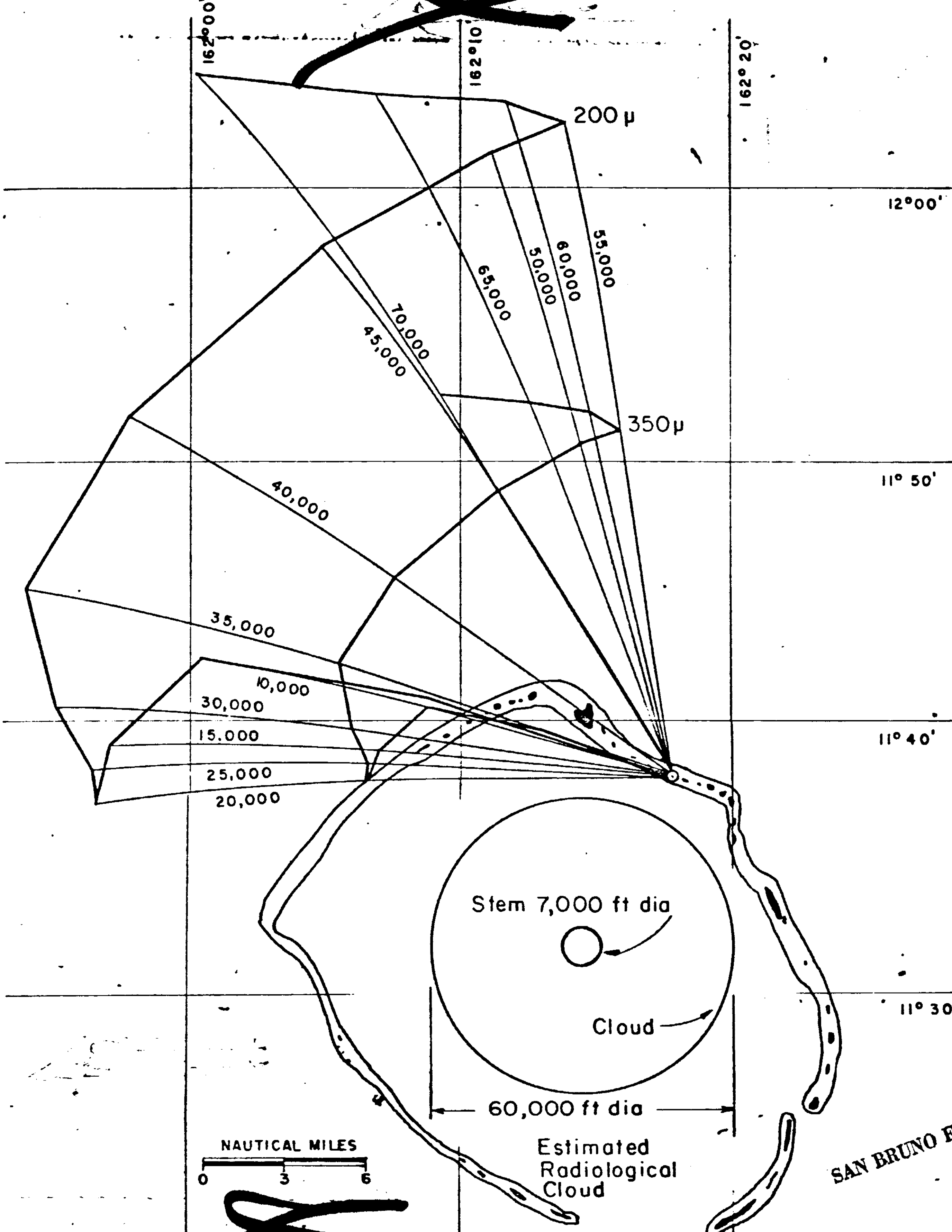

Figure 3.15 Mohawk Particle Fall Plot.

of accuracy and interpretation discussed in Section 3.1.1.3.

3.1.3.3 Land Equivalent Distribution of Fallout. Three foot high exposure rate readings were available from the Project 2.65 survey as well as the RadSafe survey of the contaminated islands. Both sets of readings were extrapolated to H+1 hour by using a $t^{-1.0}$ decay equation. The RadSafe readings at 25 feet and 50 feet altitude were converted to 3 feet readings by multiplying by 2.5 and 3.2, respectively. The resultant exposure rates are plotted as data points on a map in Figure 3.16. The observed field gamma exposure rate decay exponent was 1.1. It is interesting to note that readings near the crater, extrapolated to H+1 hour, in many cases exceeded 10,000 r/hr. These values are higher than any previous extrapolated values based on D-day measurements.

3.1.3.4 Central Time of Arrival Contours. The constructed central time of arrival contours are presented in Figure 3.17. There was no data taken relative to such measurements and these contours are presented for convenience in drawing conclusions about total exposure only.

3.1.4 Tewa. **BEST AVAILABLE COPY**

3.1.4.1 Introduction. The Tewa device was detonated on a barge in shallow water over the lagoon reef between Sites Charlie and Dog, Bikini Atoll, at 0546M, 21 July 1956. The yield of the device was measured to be [redacted] of which [redacted]

The environment prior to firing Tewa is illustrated in Figure 3.18. Aerial photographs show that a crater of about 3,200 feet in diameter was produced in the reef. Considering the shallowness of the water over the reef (0-60 feet), the explosive size of the weapon, and the crater size, Tewa is considered as a land surface shot. With careful analysis it may be found that the lagoon water introduced differences in the effects anticipated from a land surface burst. However, it is expected that these differences will be small.

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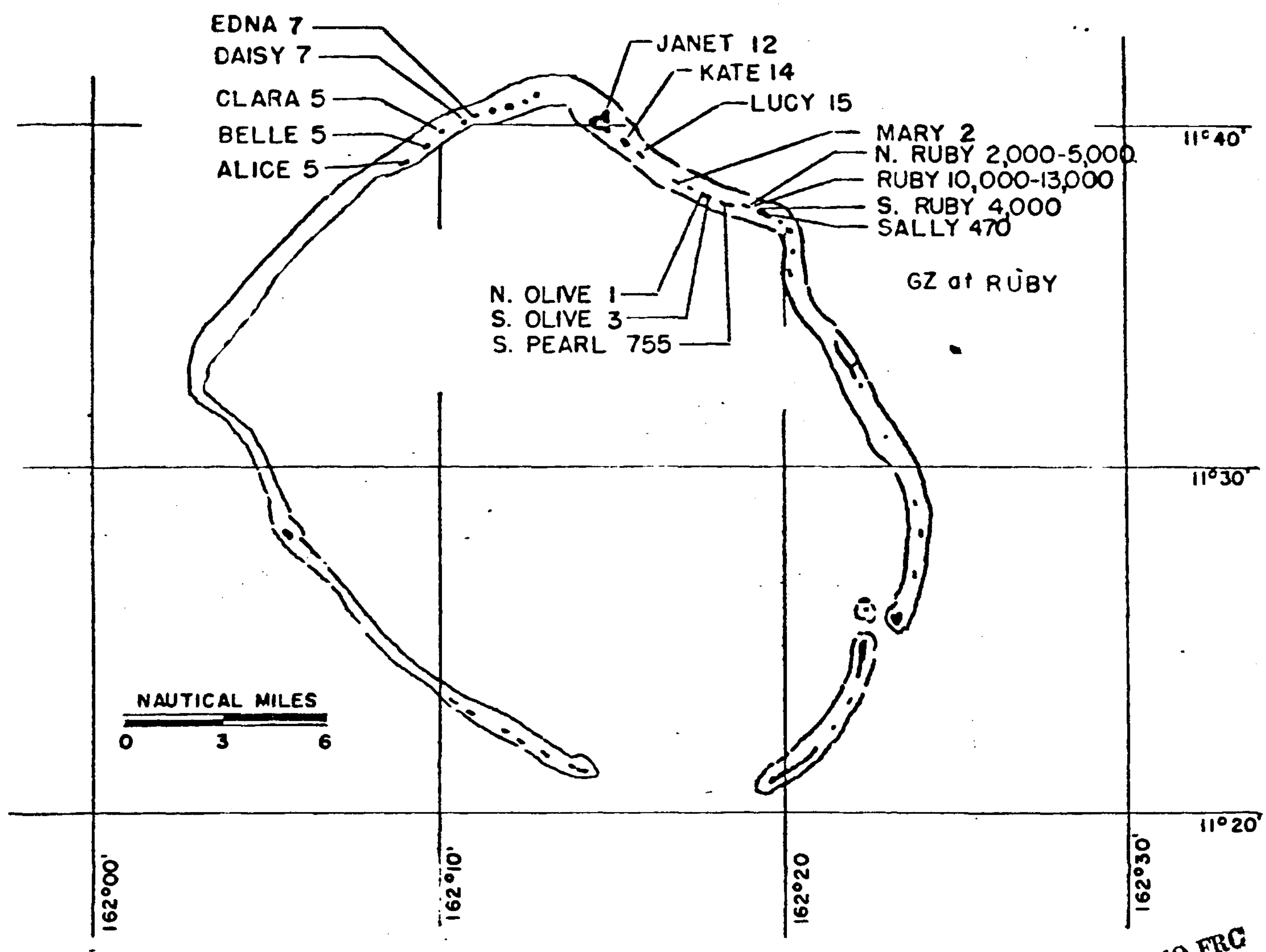

Fig 3.16

Figure 3.16 Mohawk Fallout Radiation Plot. H+1 Hour equivalent land exposure rates in r/hr.

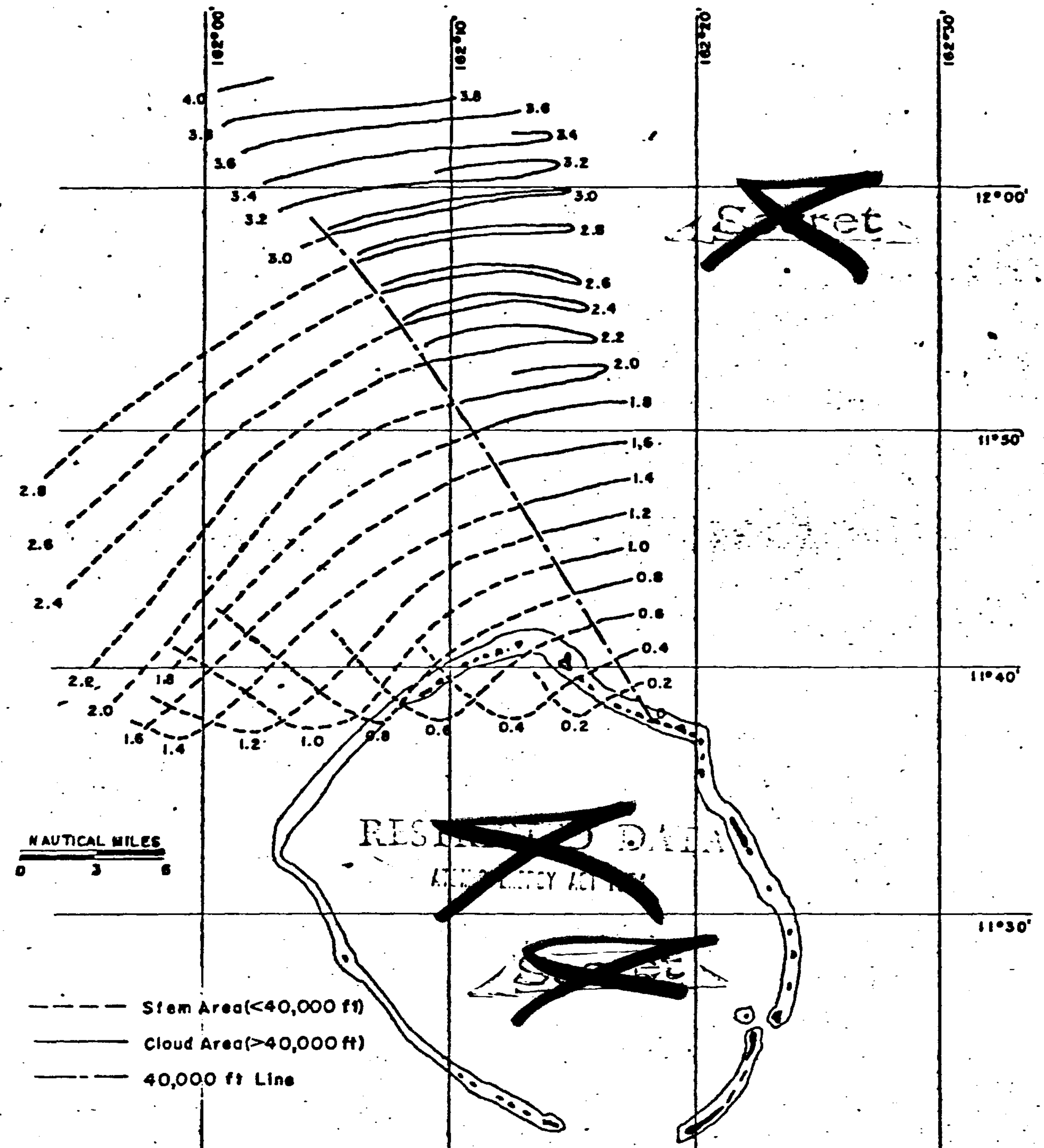

Figure 3.17 Mohawk Central Time of Arrival Plot. Times in hours.

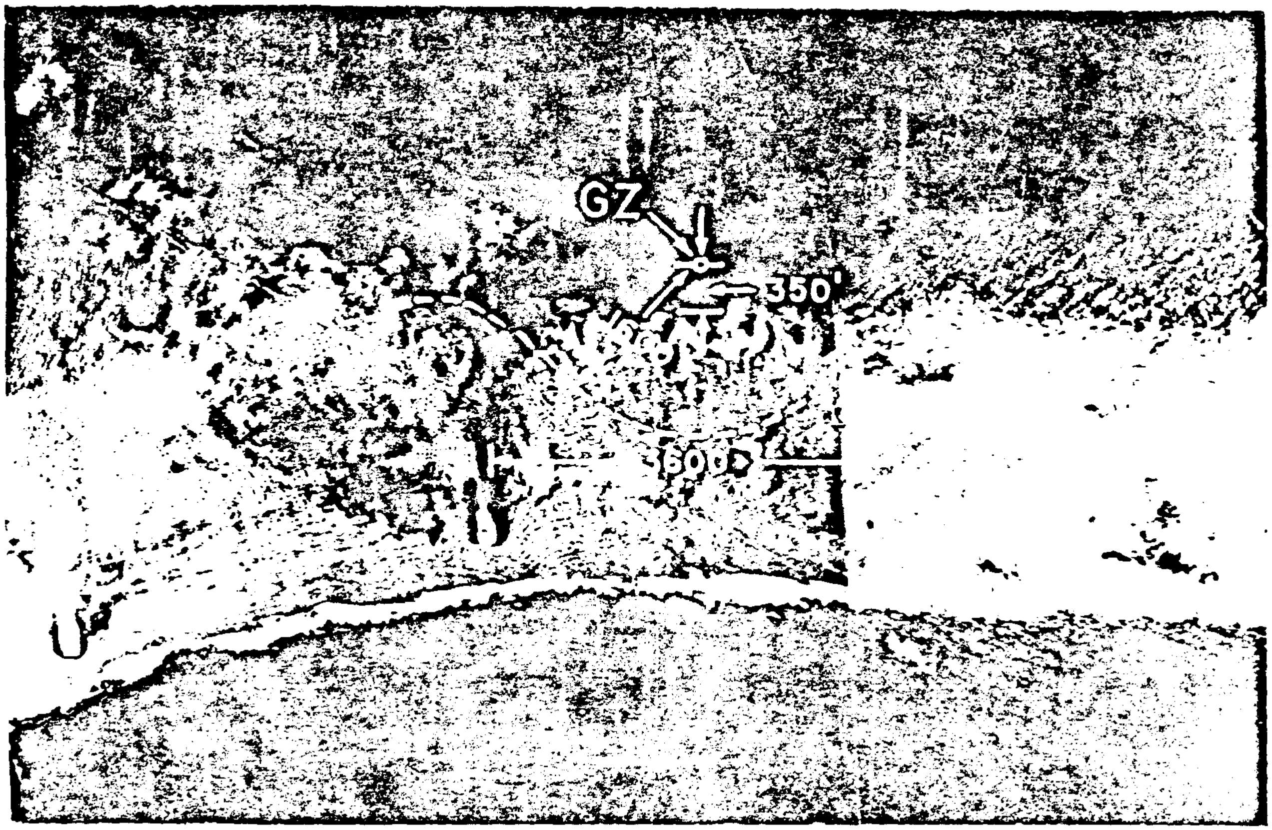

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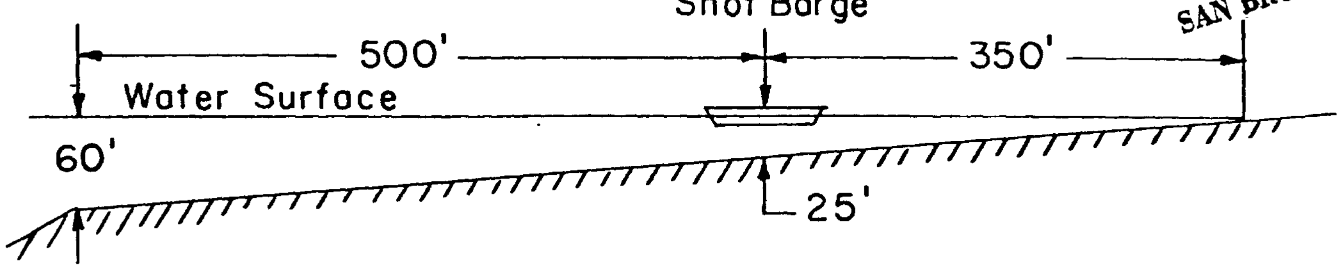
Figure 3.18 Aerial View of Reef Between Sites Charlie and Dog with an Overlay of the Tewa Crater.

88



3.1.4.2 Distribution of Activity in the Stabilized Cloud. Limited radiation measurements were made in the nuclear cloud with four (4) rockets fired at about H+7 minutes. Subject to the limitations given in Section 3.1.1.2, the reduced radiation rate readings from the only record analyzed in the field are presented in Figure 3.19. A view showing the location of the plane of the rockets in the cloud is presented in Figure 3.20. The dimensions which were used were obtained from photographs of the Navajo mushroom taken at H+8 minutes.

3.1.4.3 Particle Fall Plot. Figure 3.21 represents the particle fall plot for the winds measured at and after shot time for the Tewa event. The comments and limitations previously given in Section 3.1.1.3 are equally applicable to this plot.

3.1.4.4 Characterization of Fallout Material. In general, the fall-out material closely resembled that from the Zuni Shot as well as that from CASTLE Bravo. Particle size and chemical analyses will be performed almost exclusively in continental laboratories and therefore such data was not available at the time of writing of this report.

3.1.4.5 Land Equivalent Distribution of Fallout [illegible]. The fall-out documentation projects in Program 2 participated fully in the Tewa event and the radiation data from the collection of material and surveys is summarized in Figure 3.22. The data are from the same sources and were treated in the same manner as discussed in Section 3.1.1.5. The radiation versus depth profiles indicated an effective depth of penetration of activity in the ocean water varying linearly from 20 meters at 10 hours to 62 meters at 38 hours and remaining constant beyond this time. The decay exponent measured in the decay tank on the M/V HORIZON

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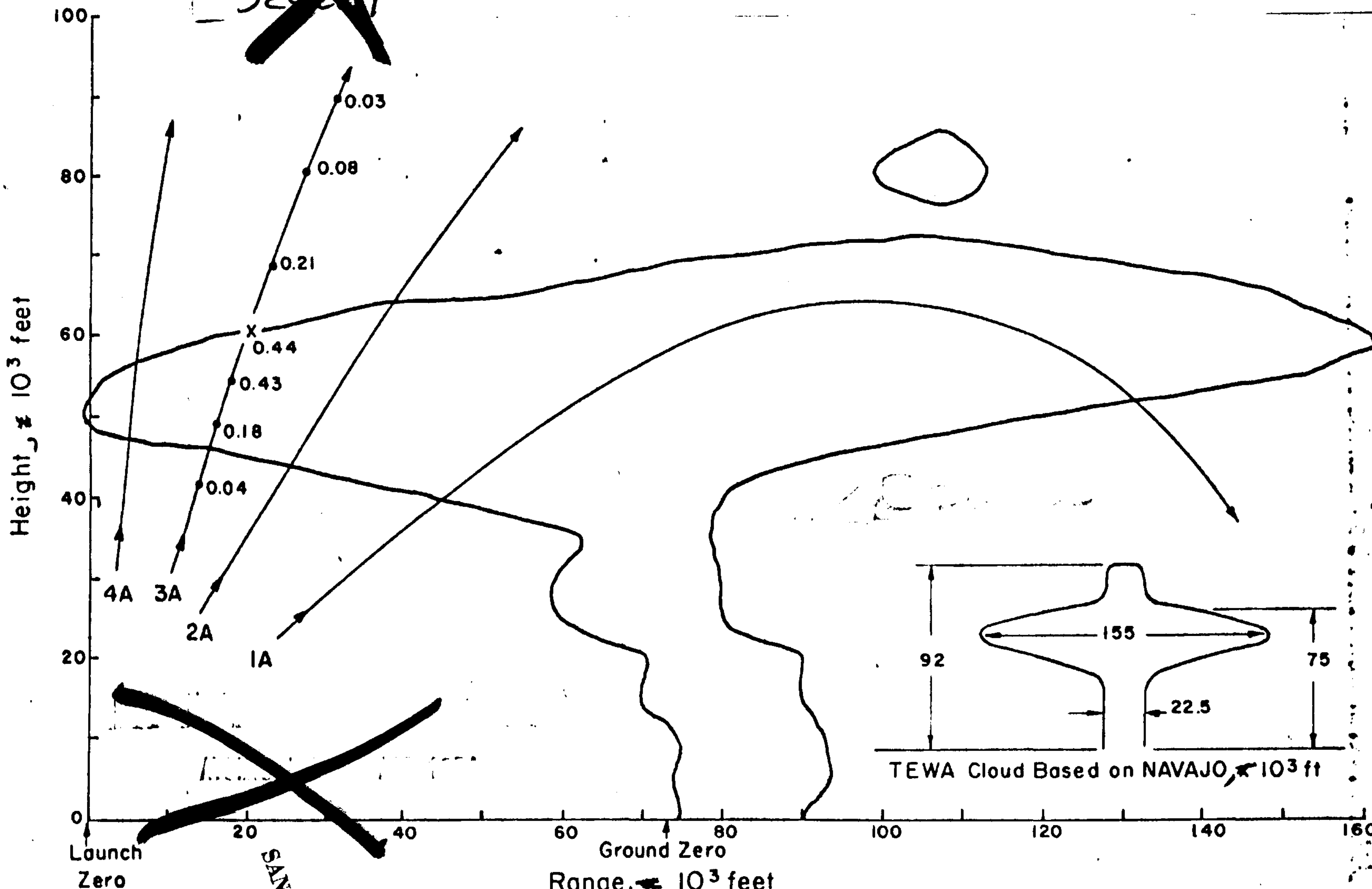
Figure 3.19 Tewa Cloud at H+7 Minutes in the Plane of the Rocket Trajectories. Readings along trajectories are corrected to sea level and are in units of 10^3 r/hr. Peak readings are denoted with an x.



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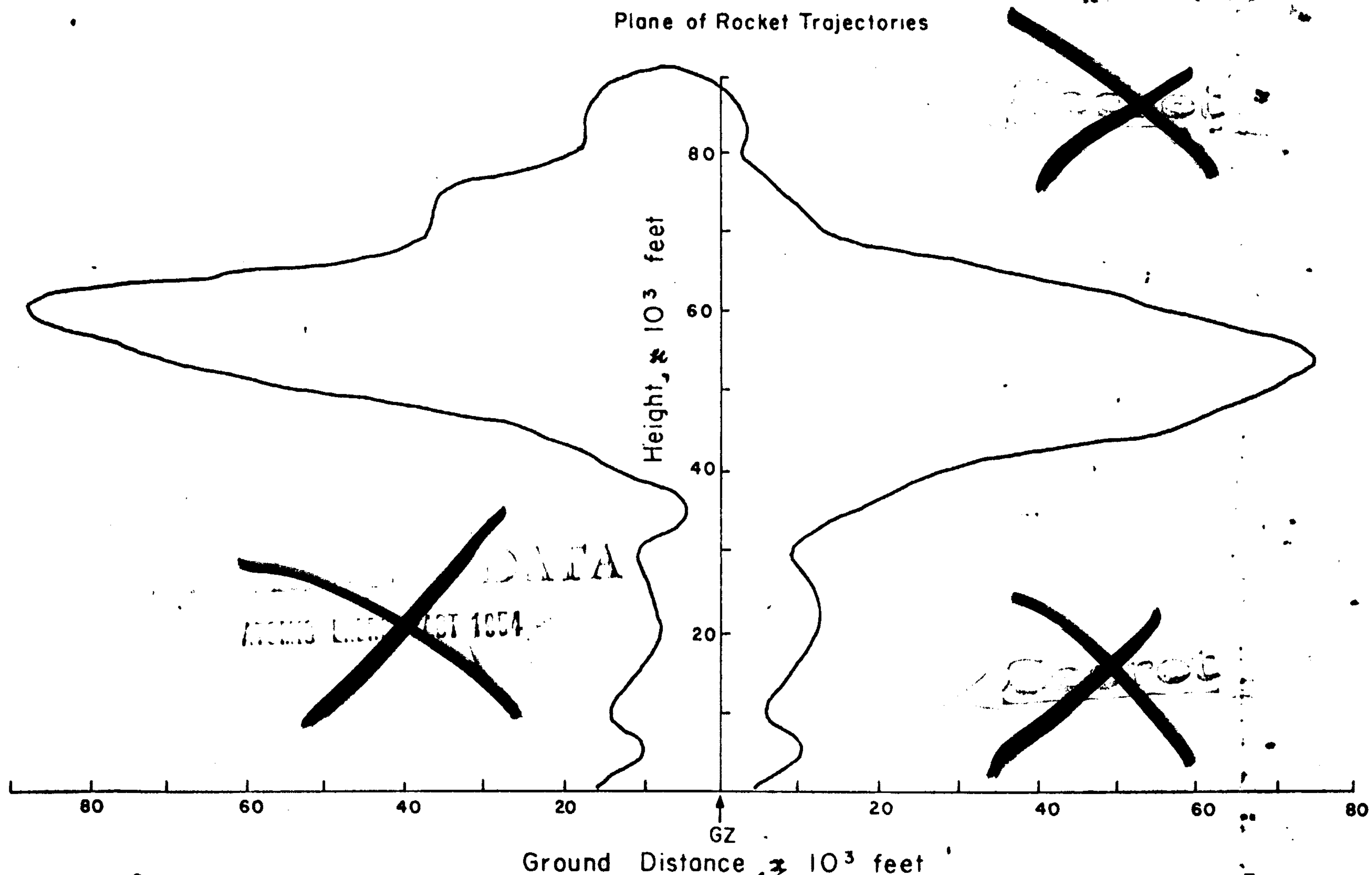
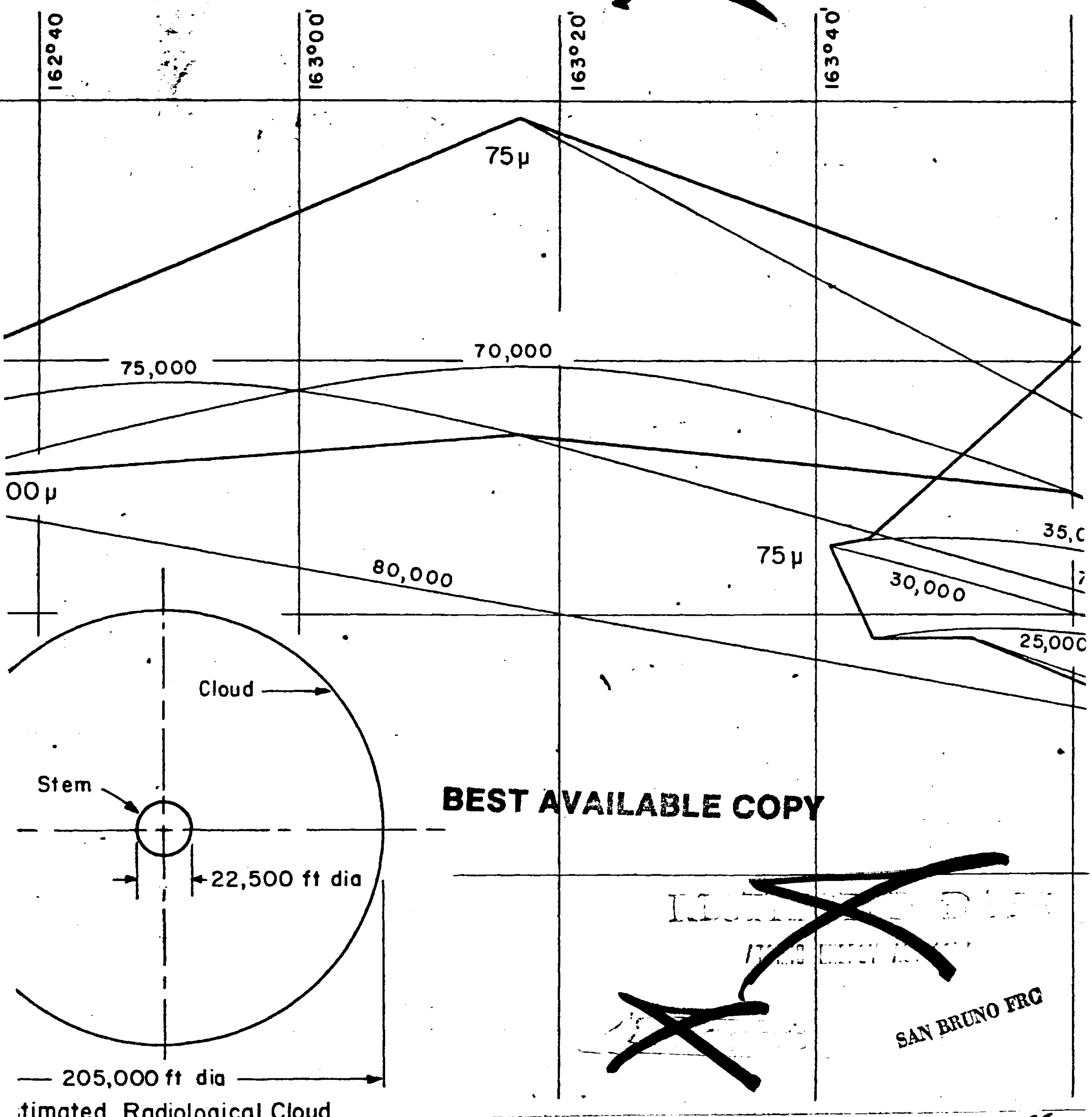


Figure 3.20 Looking Along Plane of H+7 Minutes Rockets Toward Tewa Cloud.



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92 Figure 3.21 Tewa Particle Fall Plot.

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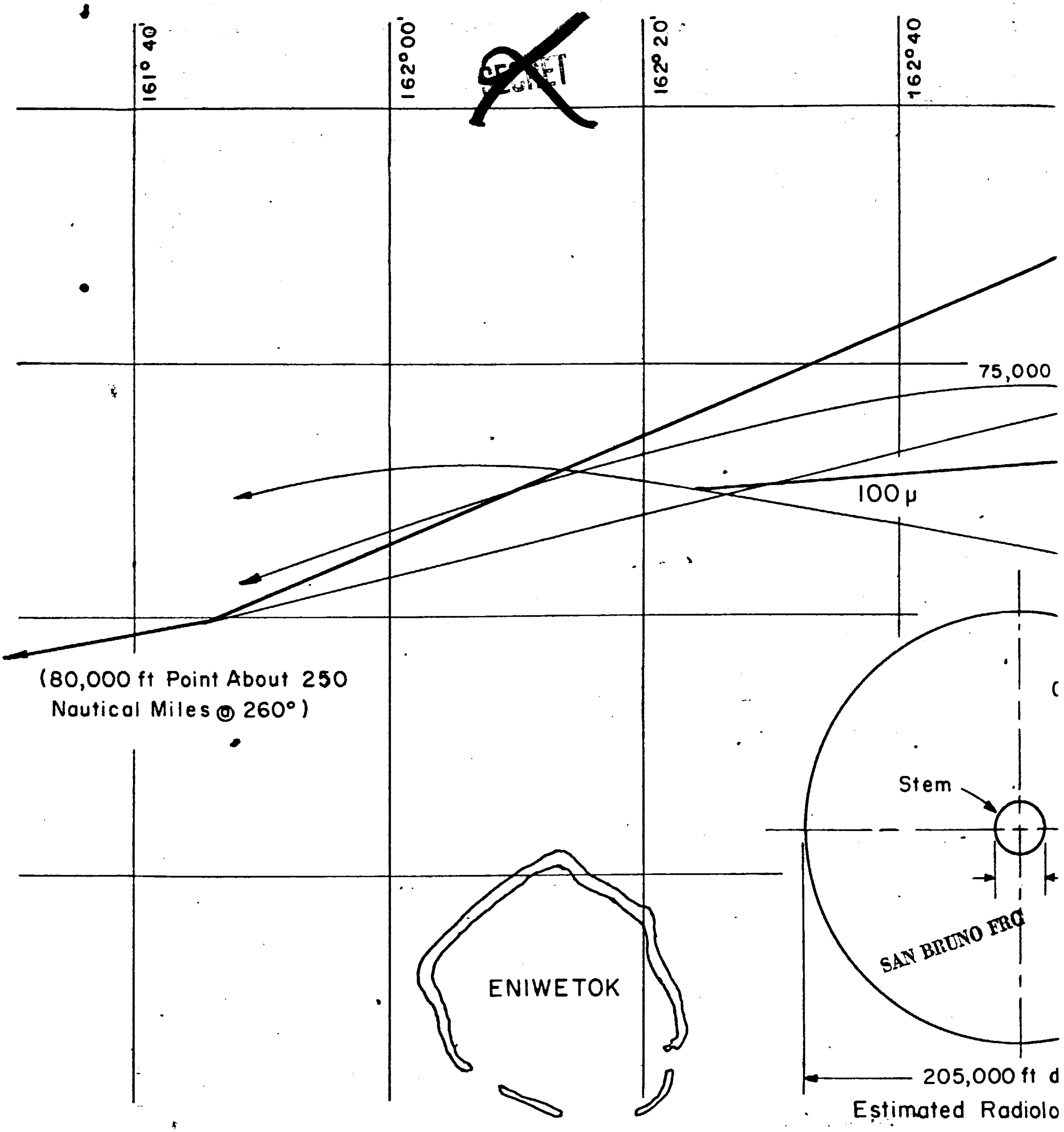

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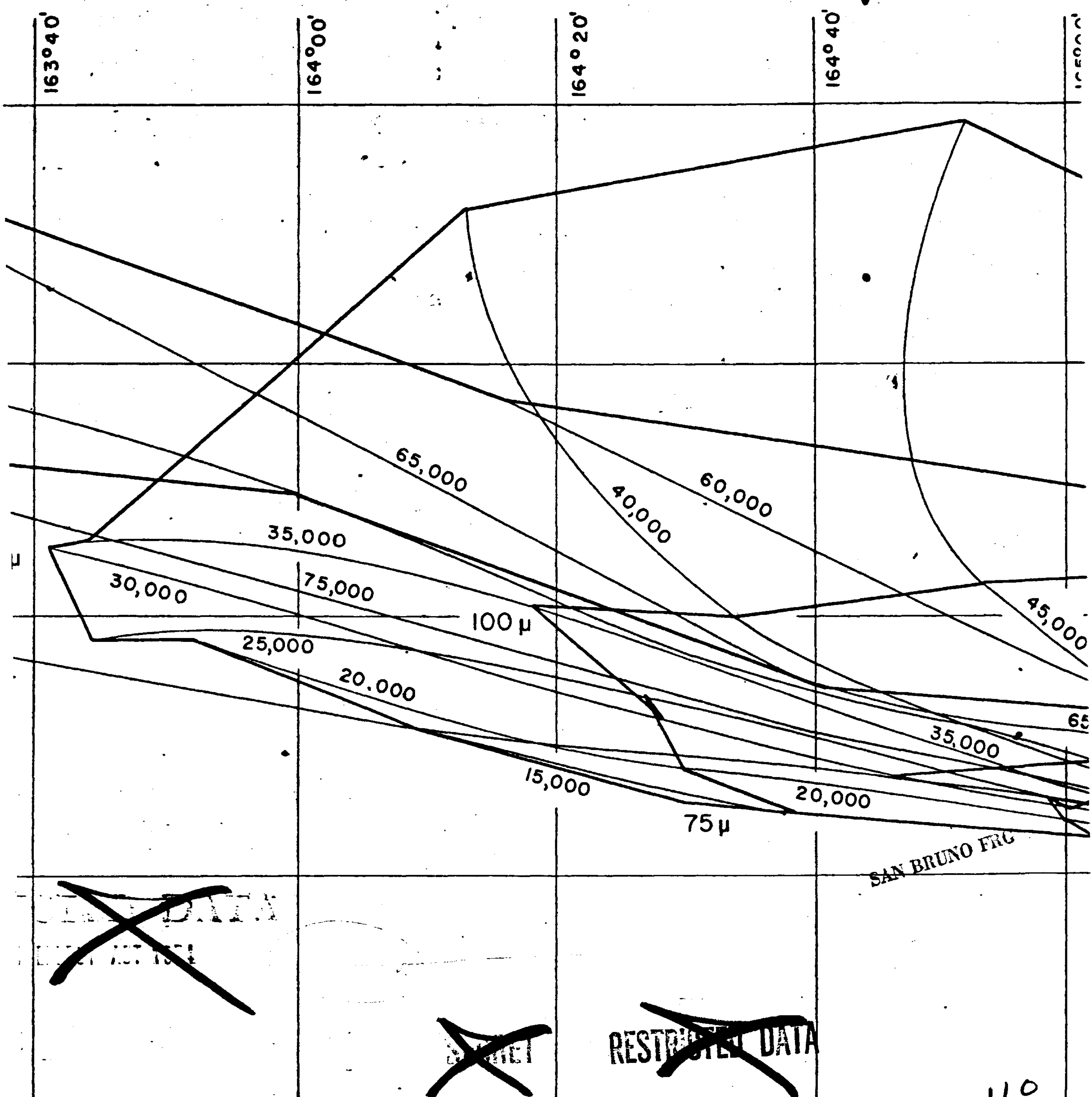

92b

110

ticle Fall Plot.

TEWA

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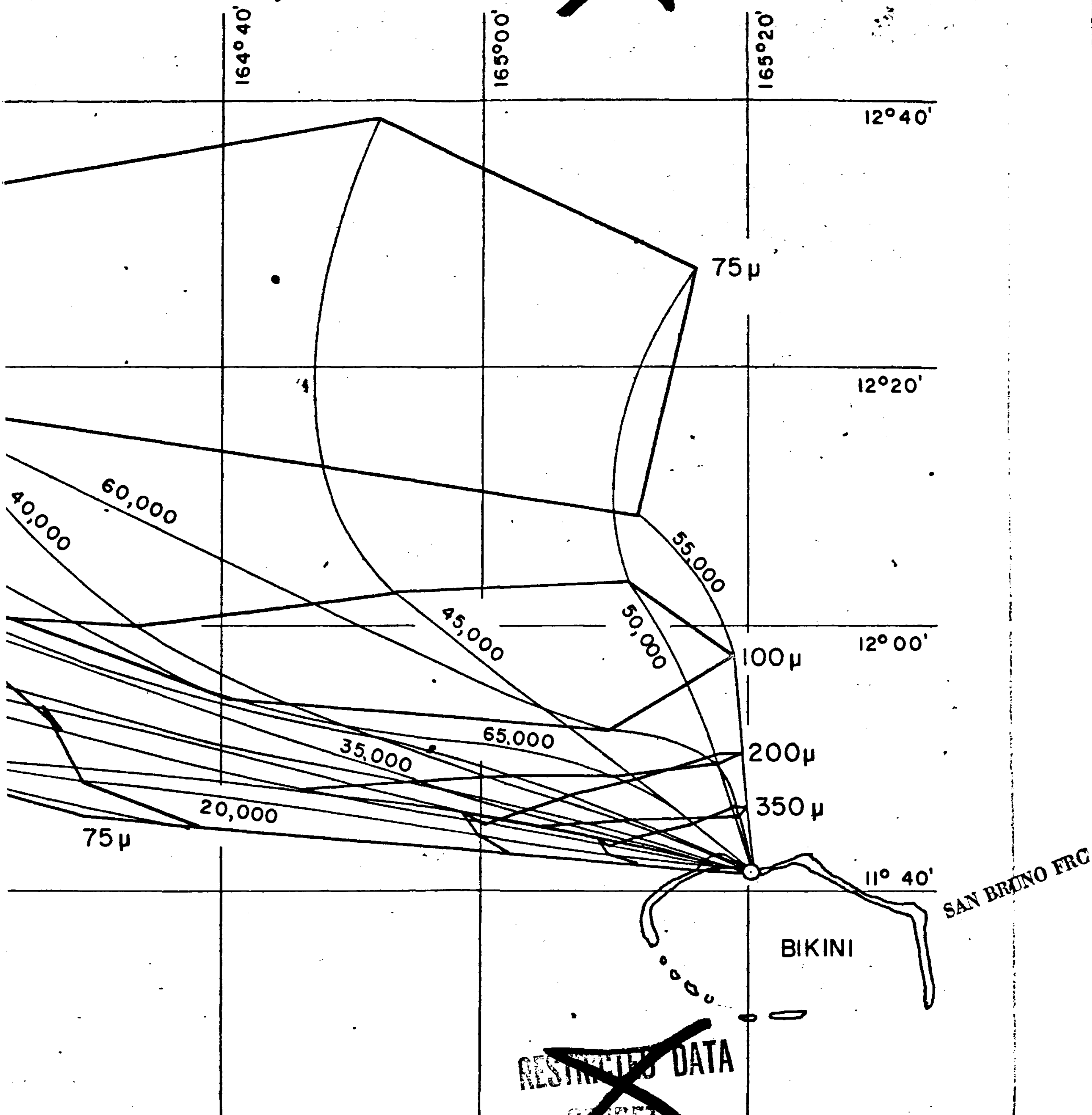

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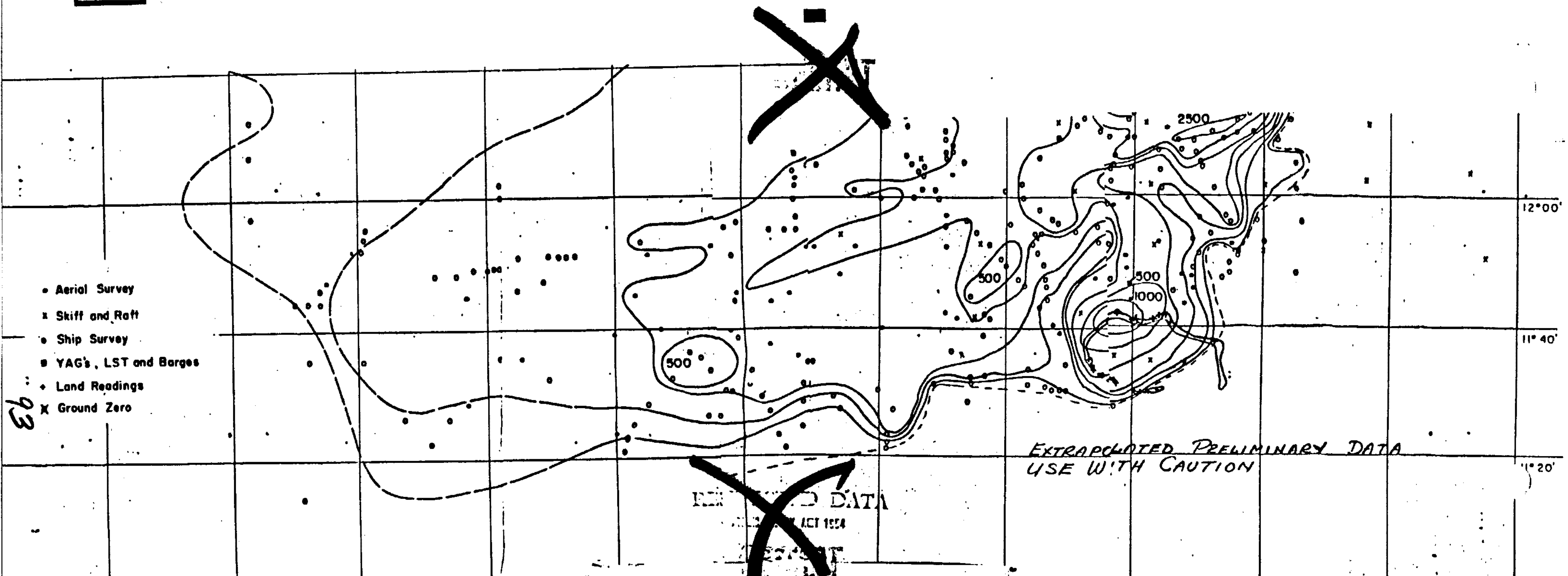

Figure 3.22 Koon Fallout Radiation Plot. H+1 hour equivalent land exposure rates in r/hr. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.

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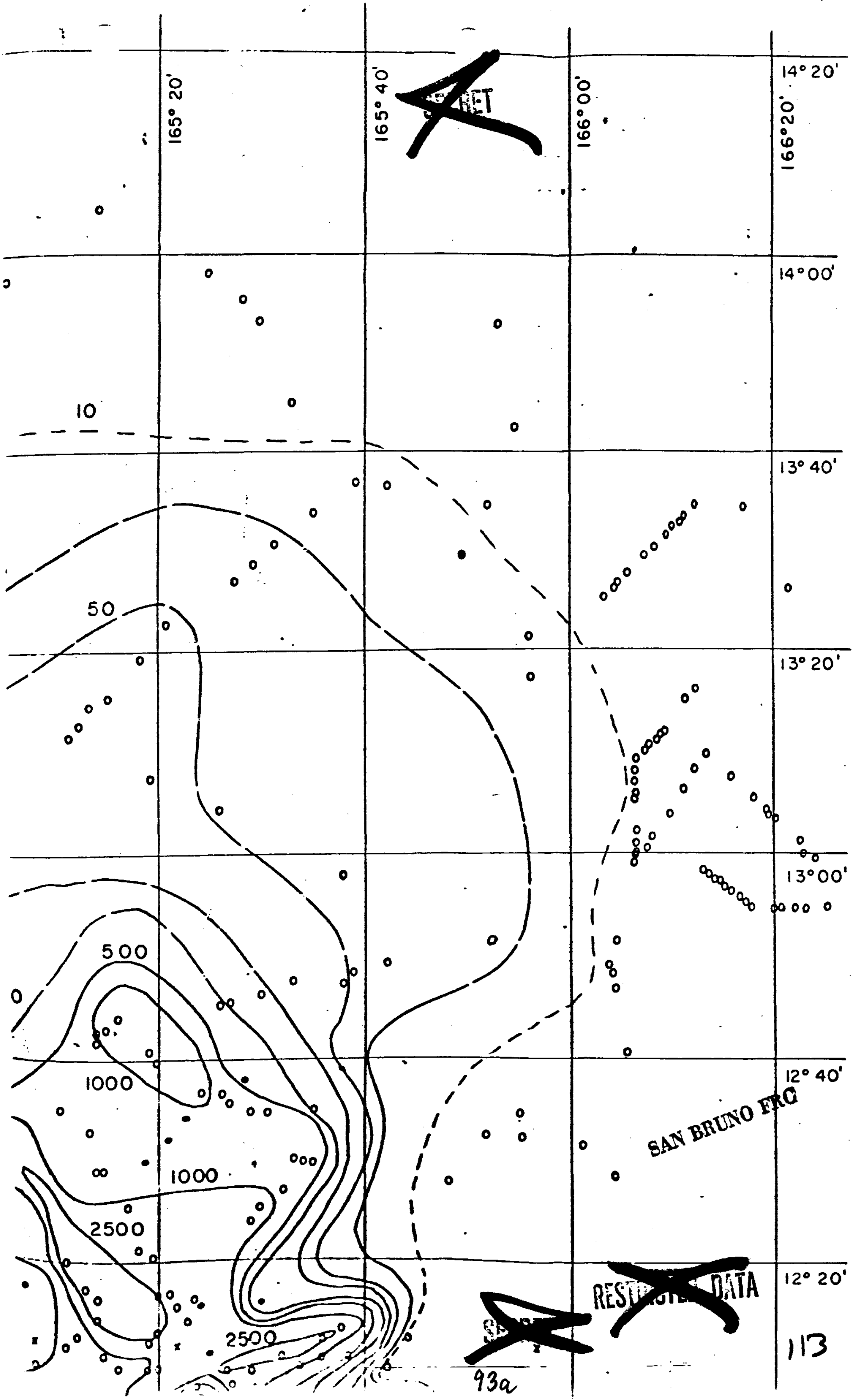

165° 20'
165° 40'
166° 00'
166°20'
14° 20'
14° 00'
13° 40'
13° 20'
13° 00'
12° 40'
12° 20'
10
50
500
1000
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2500
2500
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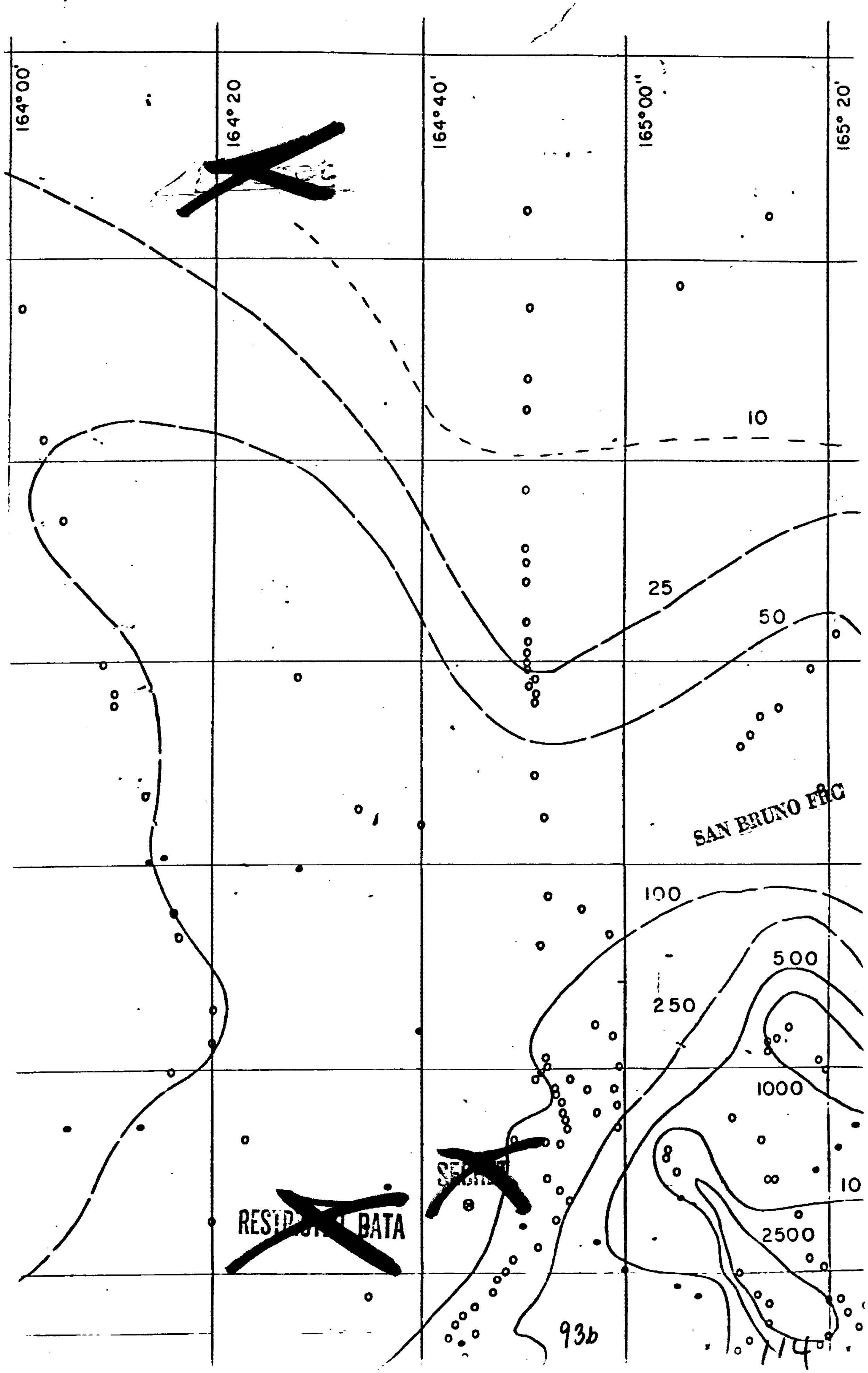
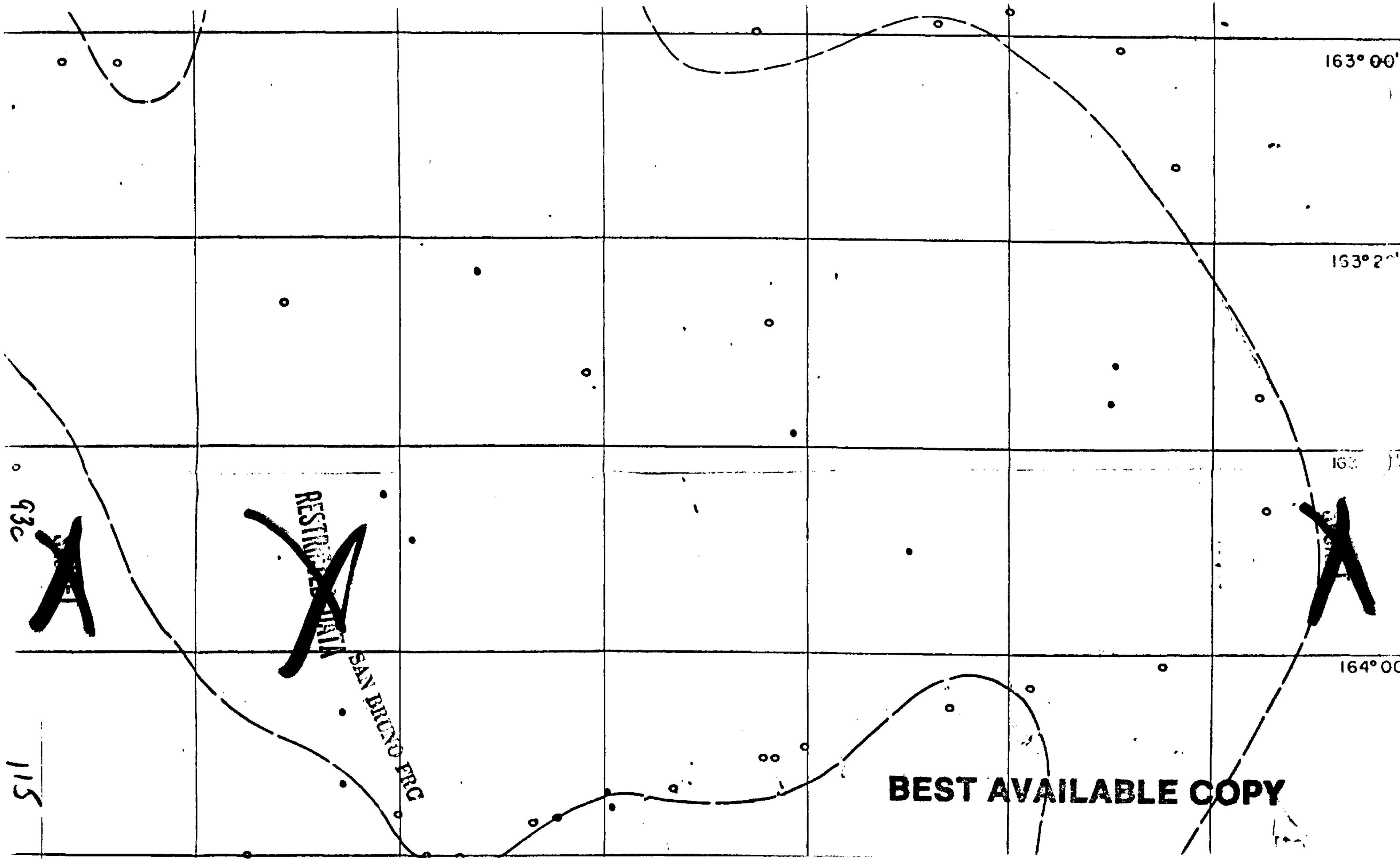
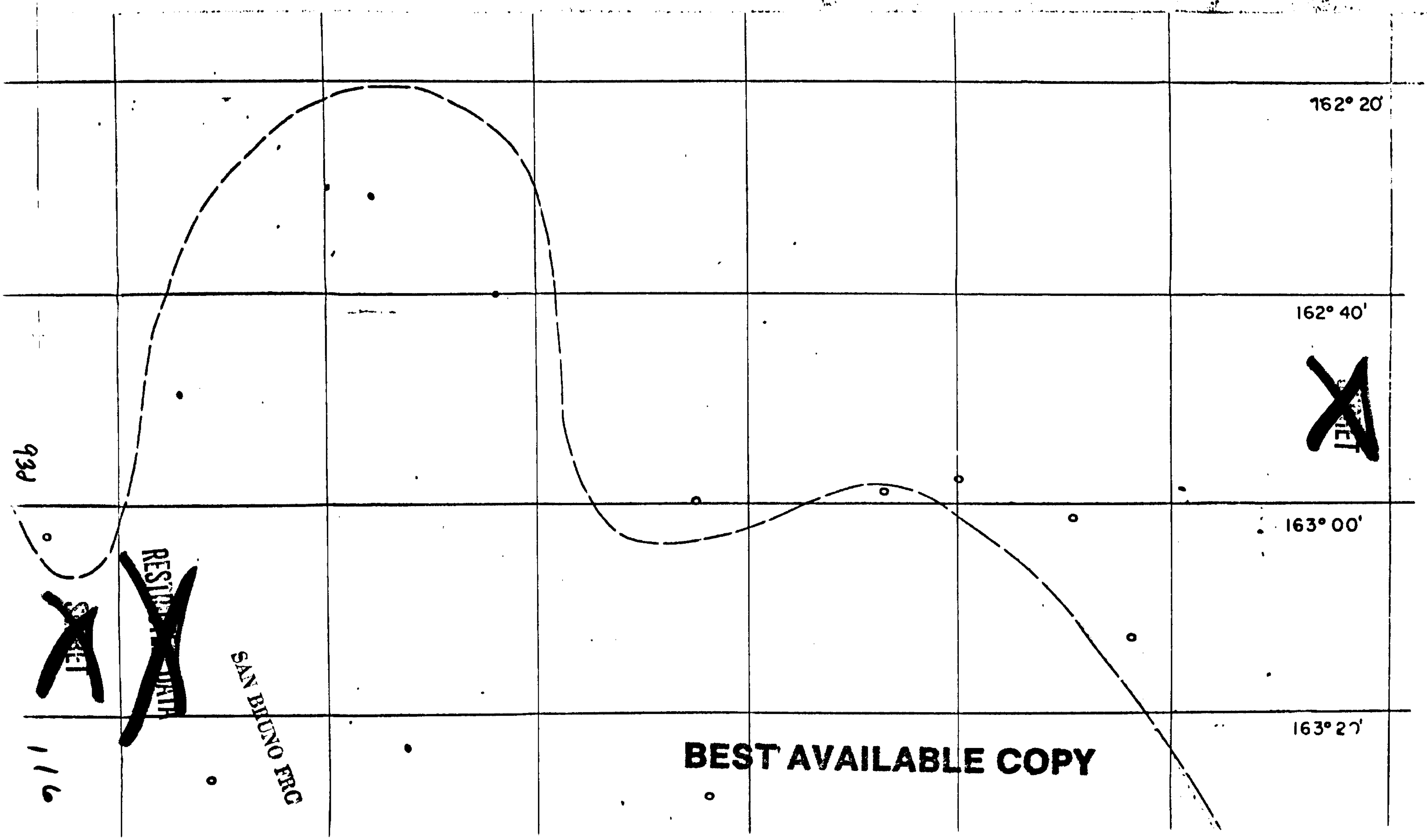
93a


164°00'
164°20
164°40'
165°00'
165° 20'
10
25
50
SAN BRUNO FRG
100
500
250
1000
2500
93b
114



93c


162° 20'
162° 40'
163° 00'
163° 2?'
93d

was 1.34. These depth of pene[illegible] and decay exponent values were used in reducing the water survey and the P2V aircraft survey readings to the land equivalent exposure rates as presented in the contours of Figure 3.22. The uncertainties in this procedure caused by the particulate nature of the fallout from a land surface burst have already been discussed in Section 3.1.1.5.

3.1.4.6 Central Time of Arrival Contours. The central time of arrival contours shown in Figure 3.23 were constructed as discussed in Section 3.1.1.6 and the same sources provided the data points.

3.1.4.7 Ten Hour Exposure Contours. The ten hour exposure contours and Project 2.1 data points are presented in Figure 3.24. The discussion of Section 3.1.1.7 is applicable to this figure.

3.1.4.8 Gross Decay Exponent. The characteristic beta and gamma decay exponents observed after the Tewa shot are summarized in Table 3.3. These should be interpreted in view of a reported Np^{239} capture to fission ratio of about 0.5. It should be emphasized that these are all preliminary values based on only part of the data and do not completely reproduce the shape of the decay curve.

TABLE 3.3 GROSS DECAY EXPONENTS FOR TEWA

	Time (Hours)	5–20	20–50	50–200
Decay Exponent	Gamma Photons*	0.7	0.7	-
	Gamma Exposure Rate	-	0.8–1.0	-
	Beta dis/min	0.9	0.9	-
	Field Gamma Exposure Rate	-	1.1	-
	Gamma Exposure Rate in Water	-	1.34	-

NOTE: *YAG 40 samples only.

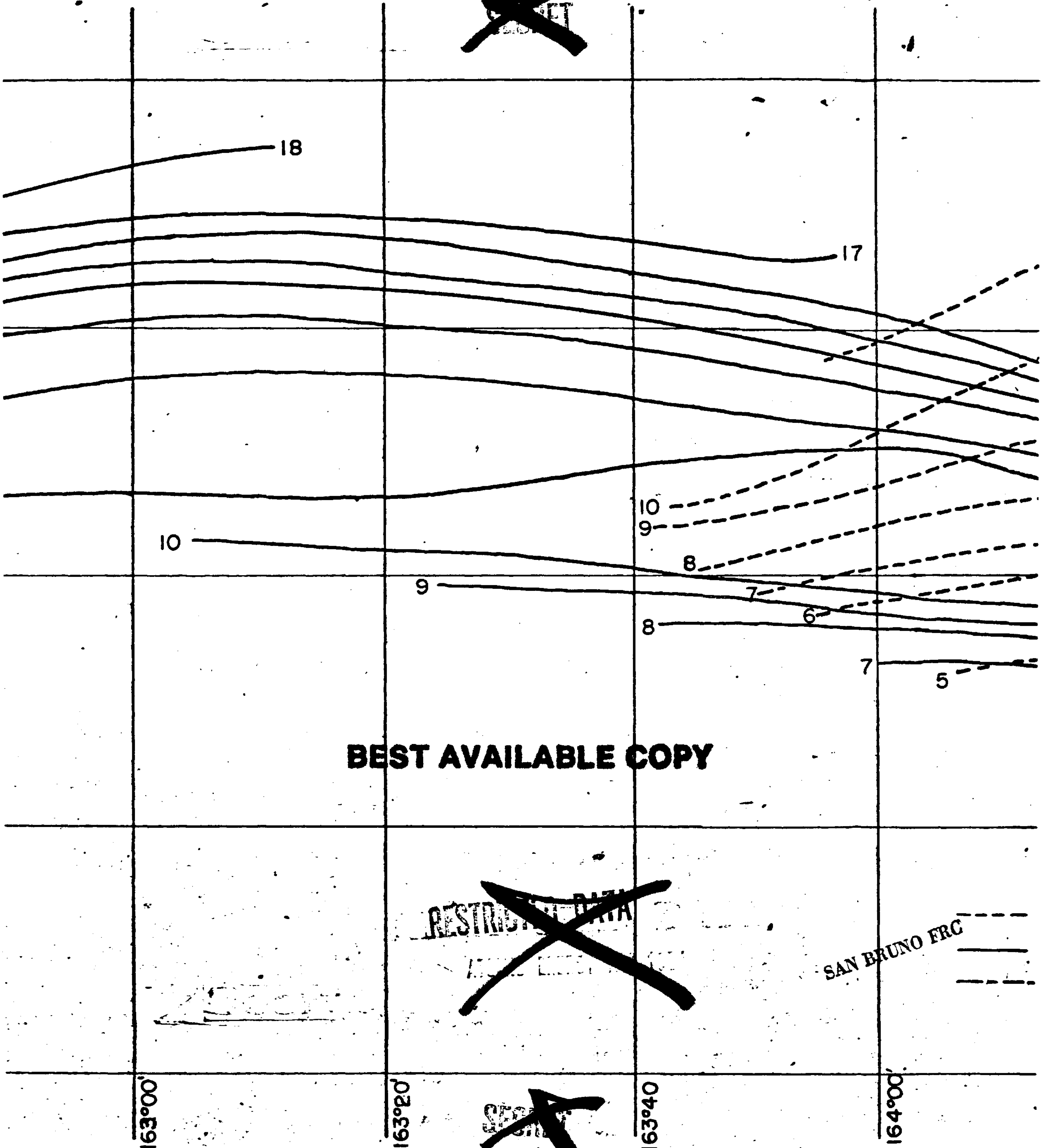


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Figure 3.23 Tewa Central Time of Arrival Plot. Times in hours.

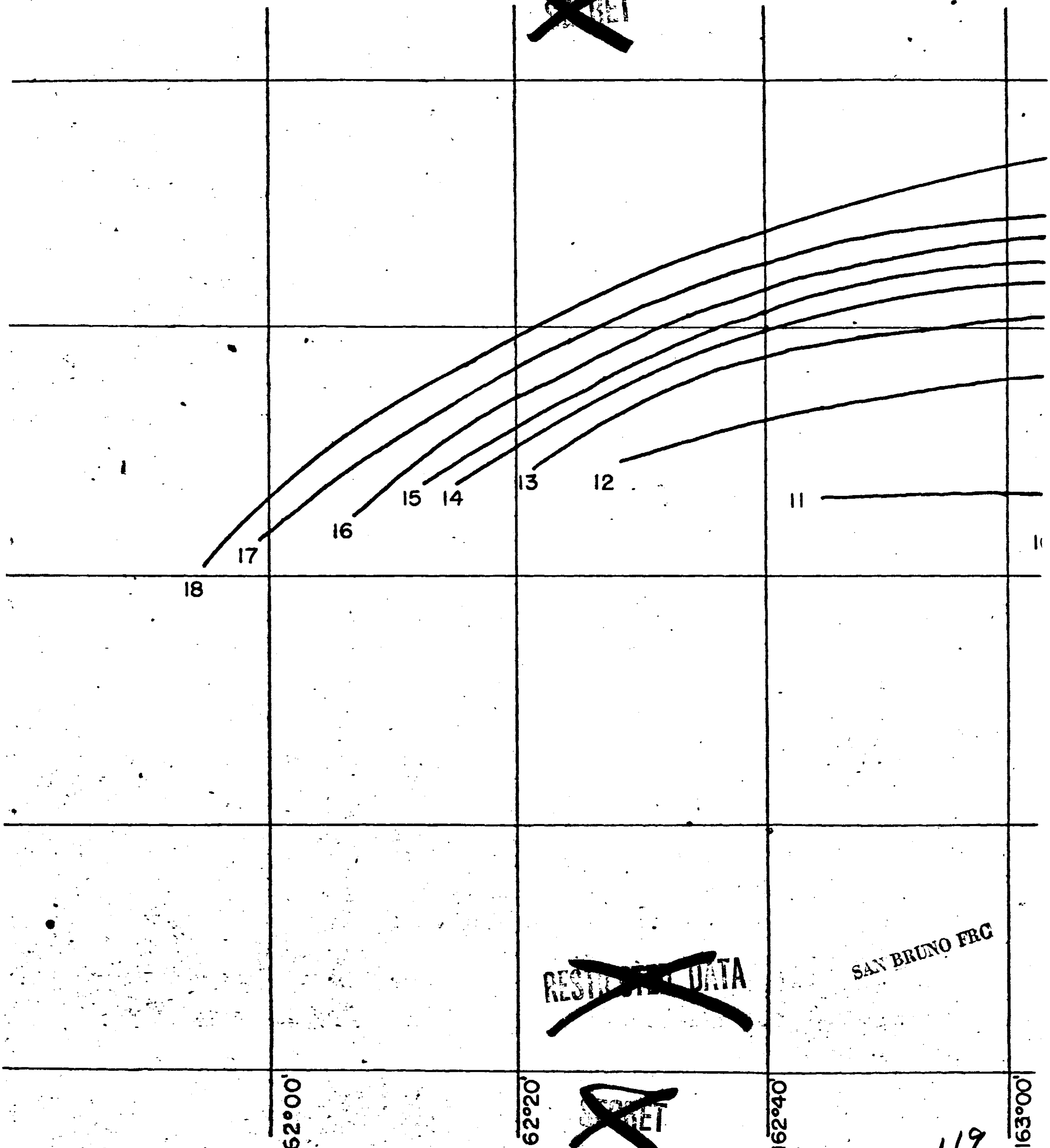
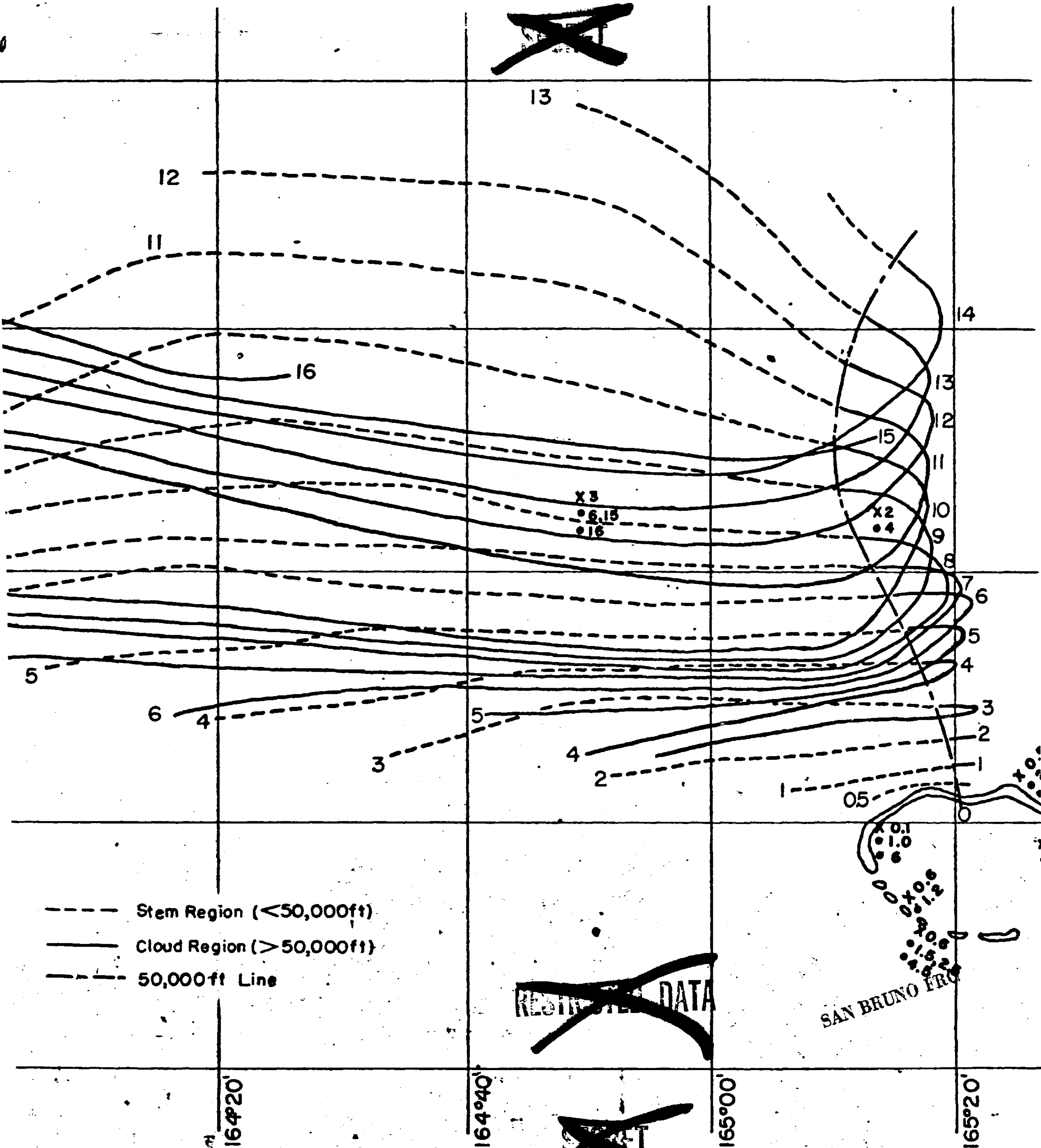
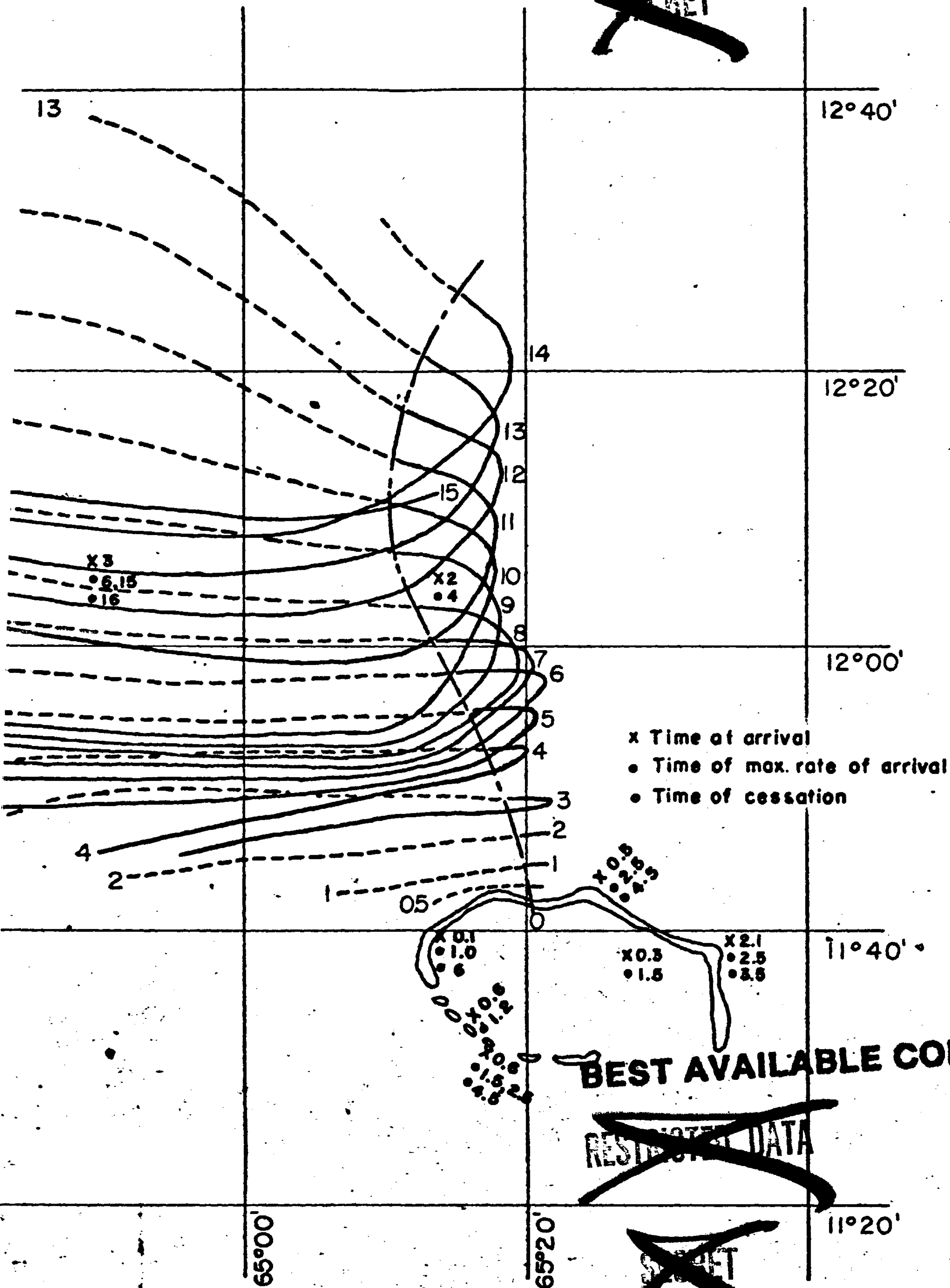


Figure 3.


Stem Region (<50,000ft)
Cloud Region (>50,000ft)
50,000ft Line
164°20'
164°40'
165°00'
165°20'

120

950



12°40'
12°20'
12°00'
11°40'
11°20'
165°00'
165°20'
x Time of arrival
• Time of max. rate of arrival
• Time of cessation

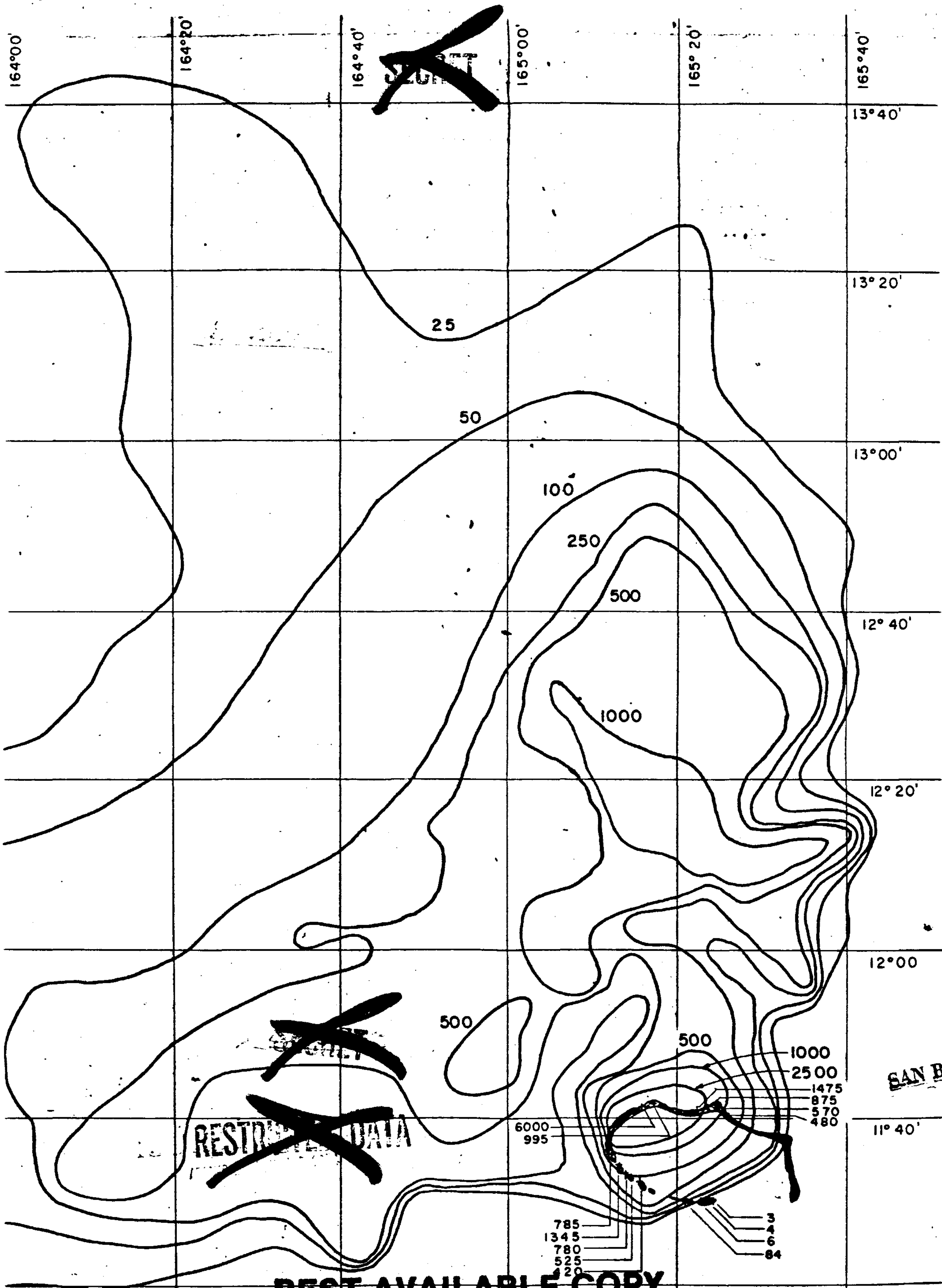


Figure 3.24 Teva Ten Hour Exposure Contours.
Exposures in r. Extrapolated Preliminary Data. Use with caution

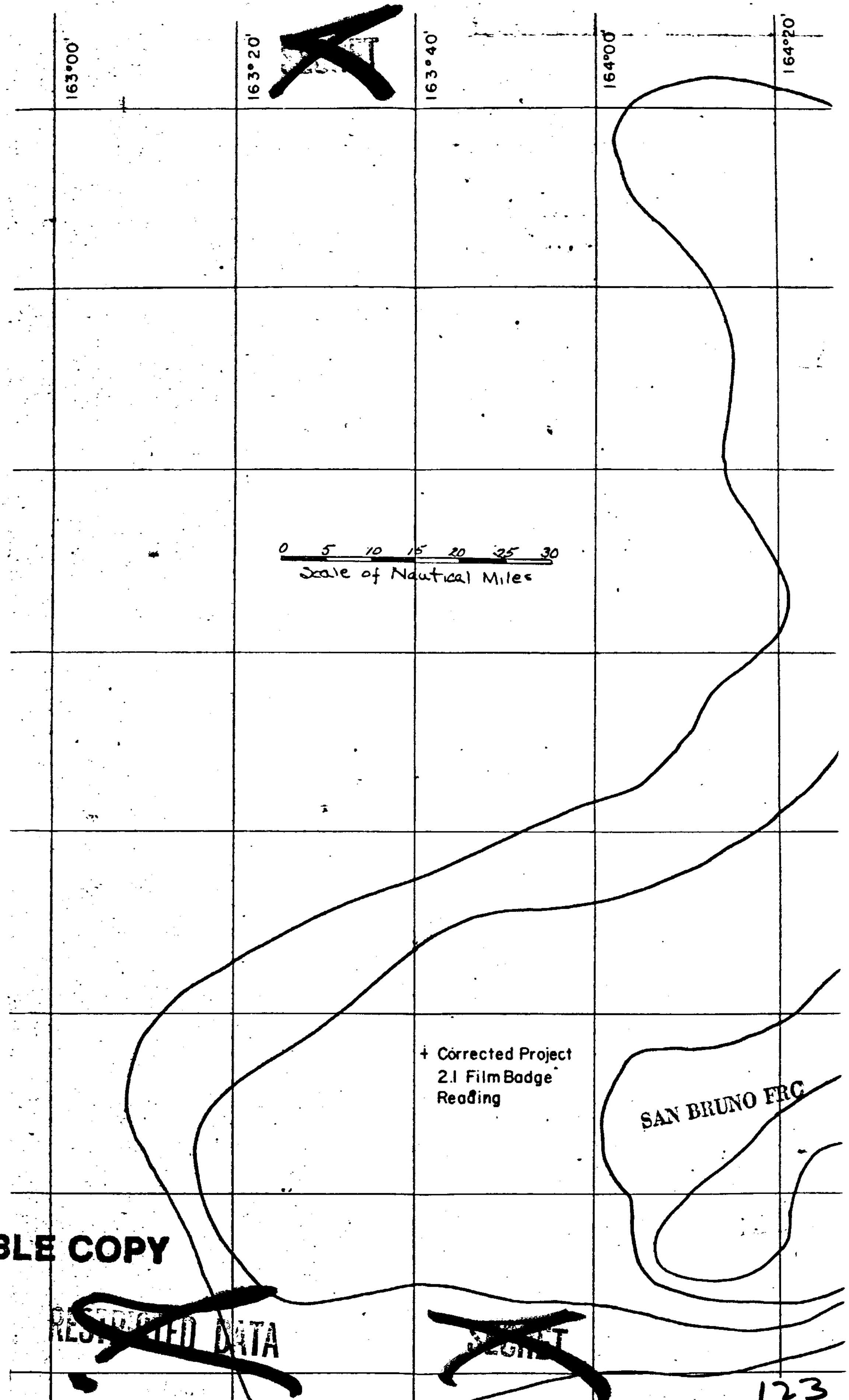


Figure 3.24 Teva Ten Hour Exposures in r. Extrapolated

3.2 AIR BURSTS

3.2.1 Cherokee.

3.2.1.1 Introduction. The Cherokee device was dropped from an aircraft on 21 May 1956, and detonated at a height of about 4,500 feet at approximately 3.7 miles northeast of Site Charlie. DELETED

DELETED

DELETED The intended burst point for the weapon was directly above Site Charlie so that the fallout data was to be applicable to a minimal air burst over land. In actual fact, the weapon detonated above the deep ocean and therefore the results of the experiments must be interpreted in that light.

3.2.1.2 Distribution of Activity in the Stabilized Cloud. Two salvos of six rockets each were fired at the Cherokee cloud at H+7 minutes and H+15 minutes respectively. Since the rockets were aimed according to the intended zero point and hence were in a plane about 3.7 miles away from the actual zero point, the lower trajectories did not intercept the small stem of the nuclear mushroom. However, the large dimensions of the cloud provided sufficient opportunity for a number of good data traces. The results are plotted in Figure 3.25 and Figure 3.27 for the 7 minute and 15 minute salvos respectively, according to the method described in Section 3.1.1.2 and using the same cloud dimensions which were developed for Zuni and a somewhat smaller stem diameter. The location of the plane of the rocket trajectories through the mushroom is illustrated in Figures 3.26 and 3.28.

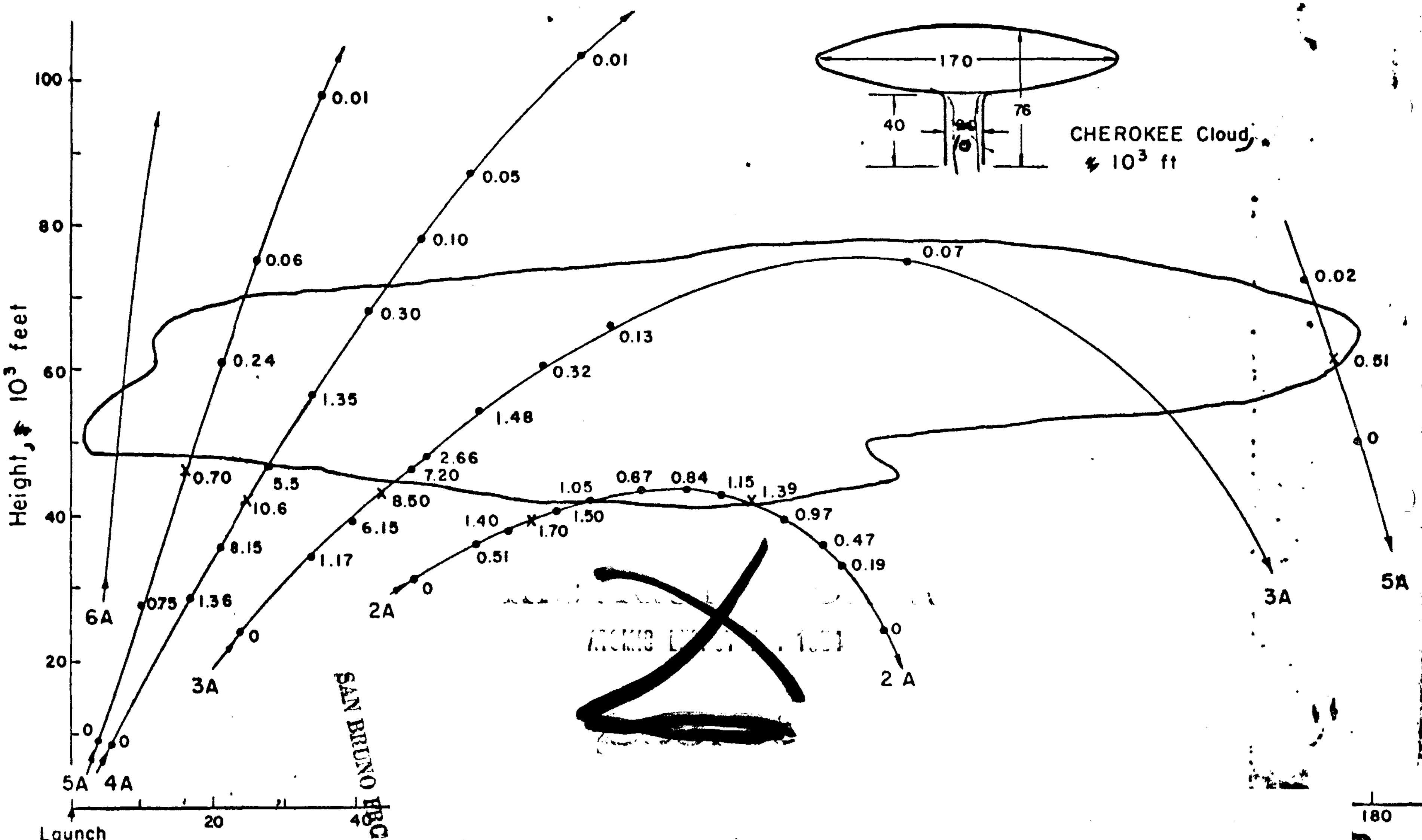


Figure 3.25 Cherokee Cloud at H+7 Minutes in the Plane of the Rocket Trajectories. Readings along trajectories are corrected to sea level and are in units of 10^3 r/hr. Peak readings are denoted with an x.

-98-

125

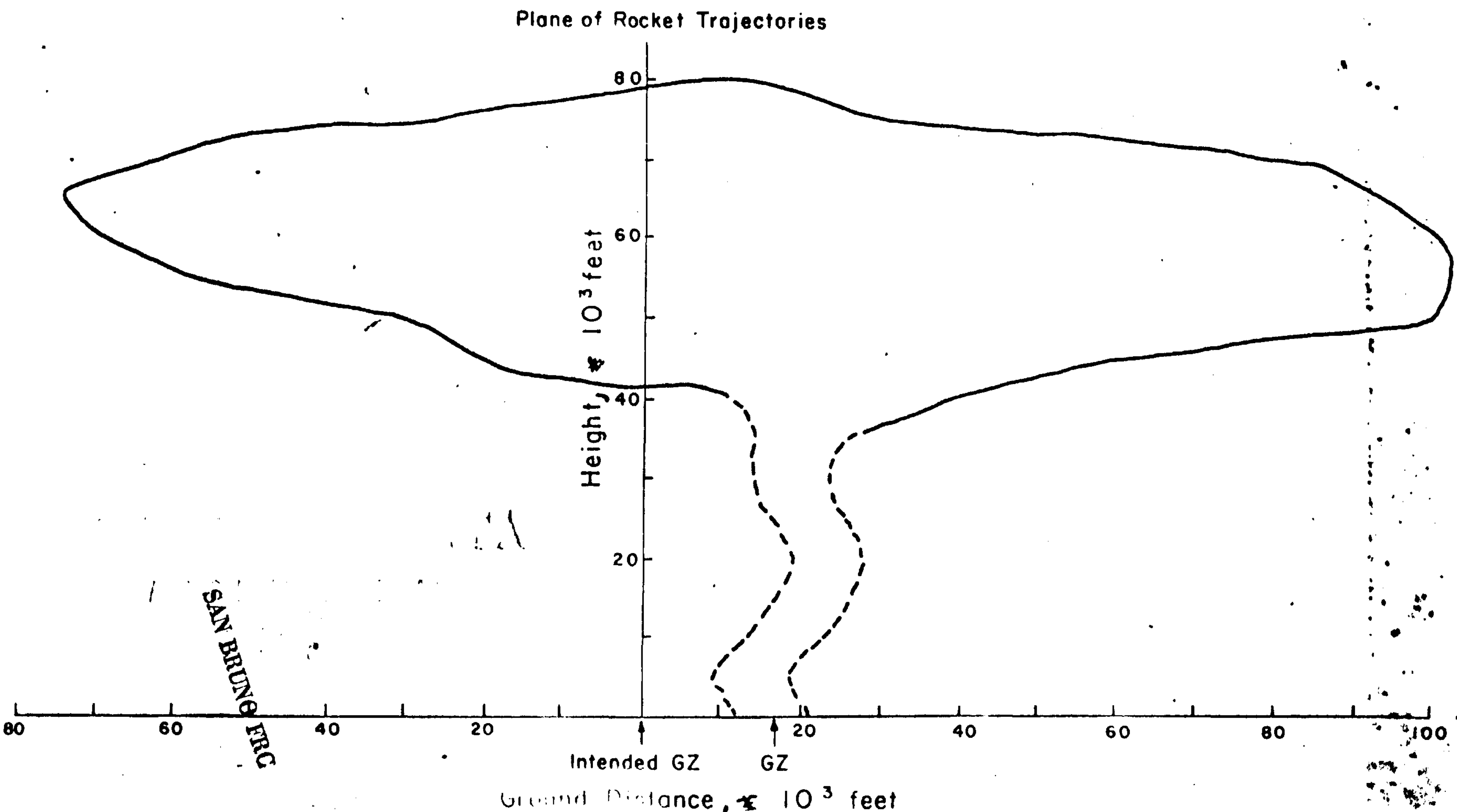
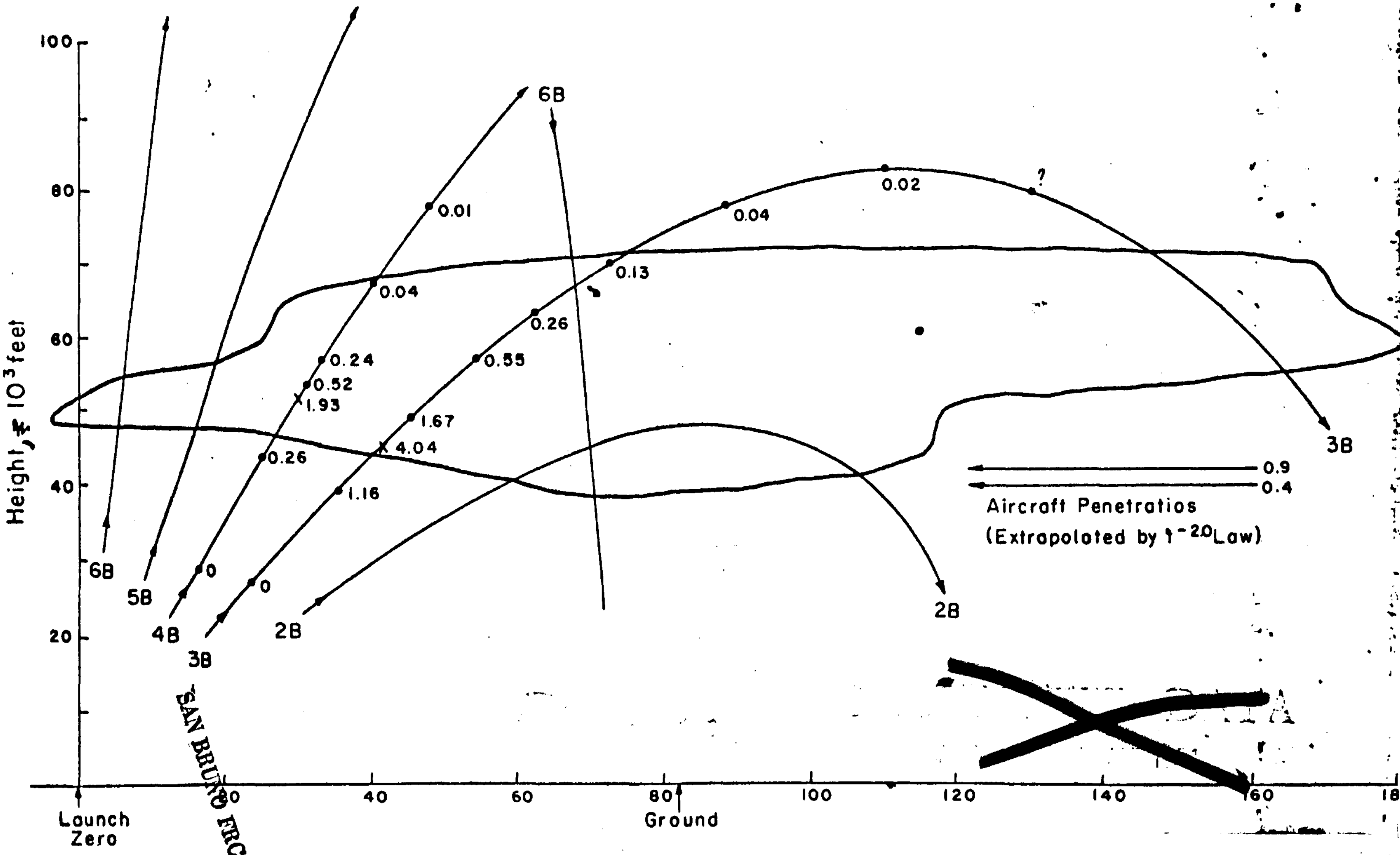


Figure 3.26 [illegible] of H+7 Minute Rockets Toward Cherokee Cloud.



Figuro 3.27 Cherokee Cloud at H+15 Minutes in the Plane of the Rocket Trajectories. Readings along trajectories are corrected to sea level and are in units of 10^3 r/hr. Peak readings are denoted with an x.

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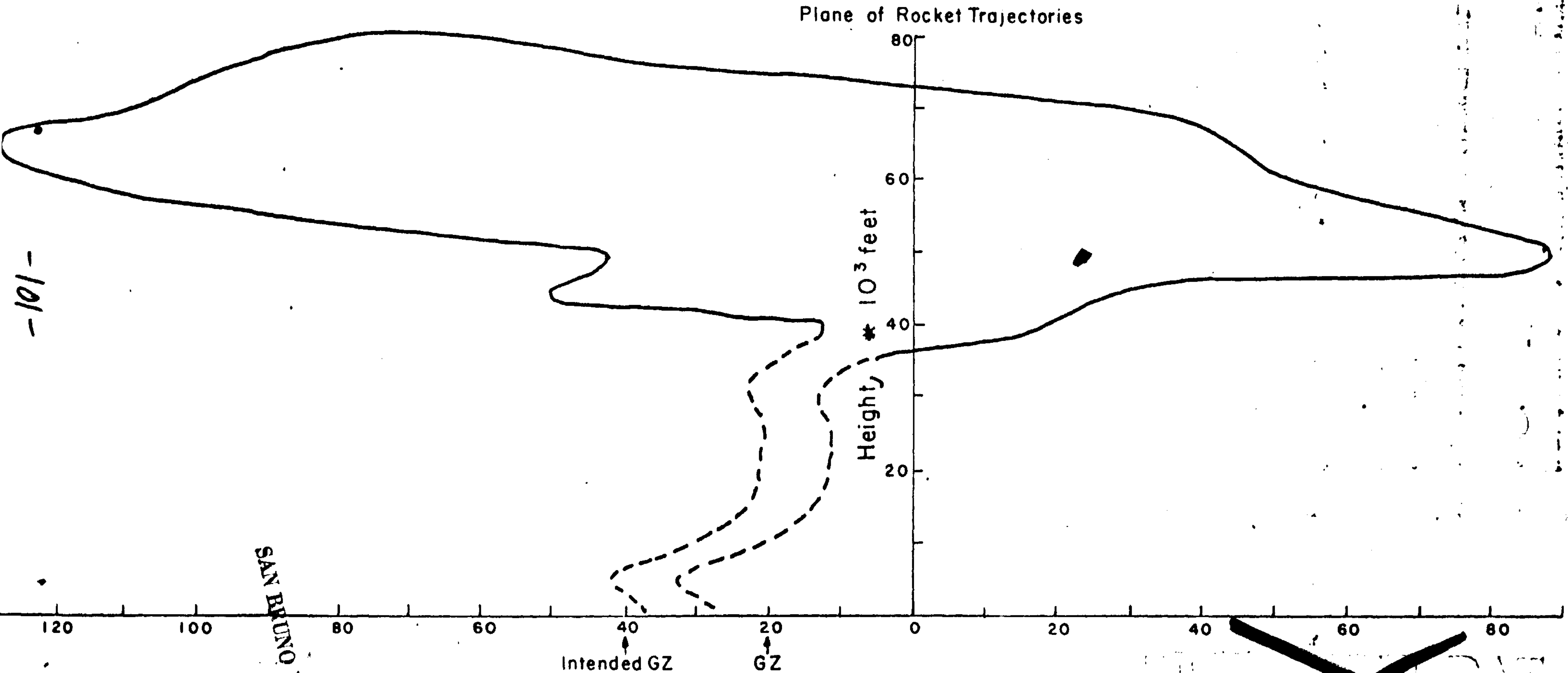

Figure 3.28 Looking Along Plane of the H/15 Minute Rockets Toward Cherokee Cloud.

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The Project 2.66 aircraft performed some penetrations at approximately H+1 hour into the lower portions of the Cherokee cloud and the readings, extrapolated back to H+15 minutes by using 2 for the decay exponent, are also presented in Figure 3.27. Visual observations from the aircraft indicated that the red-brown color, characteristic of oxides of nitrogen which are usually associated with intense radiation in nuclear clouds, was present above the flight altitudes. Therefore, the radiation fields detected by the aircraft were undoubtedly much smaller than those present at higher altitudes.

3.2.1.3 Particle Fall Plot. Figure 3.29 represents the particle fall plot for the winds measured at shot time at Bikini Atoll for the Cherokee event. No space and time variations of the wind profile have been included in this plot for two reasons; (1) the variations were not large, and (2) no appreciable fallout was experienced, so detailed correlation with position in the cloud could not be achieved. The interpretation of such a particle fall plot has been summarized in Section 3.1.1.3.

3.2.1.4 Distribution of Fallout. Figure 3.30 portrays the paths followed by the surface vessels and the aircraft through the predicted fallout area during the Cherokee fallout survey. The survey readings were essentially background levels throughout the survey. The upper limit of the land equivalent exposure rate readings in the surveyed area was less than 0.5 r/hr when extrapolated to H+1 hour by a $t^{-1.0}$ decay equation. A comparison of Figure 3.30 with Figure 3.29 indicates that it is unlikely that any major fallout areas were missed by the survey vehicles and therefore it is clear that this particular type of event

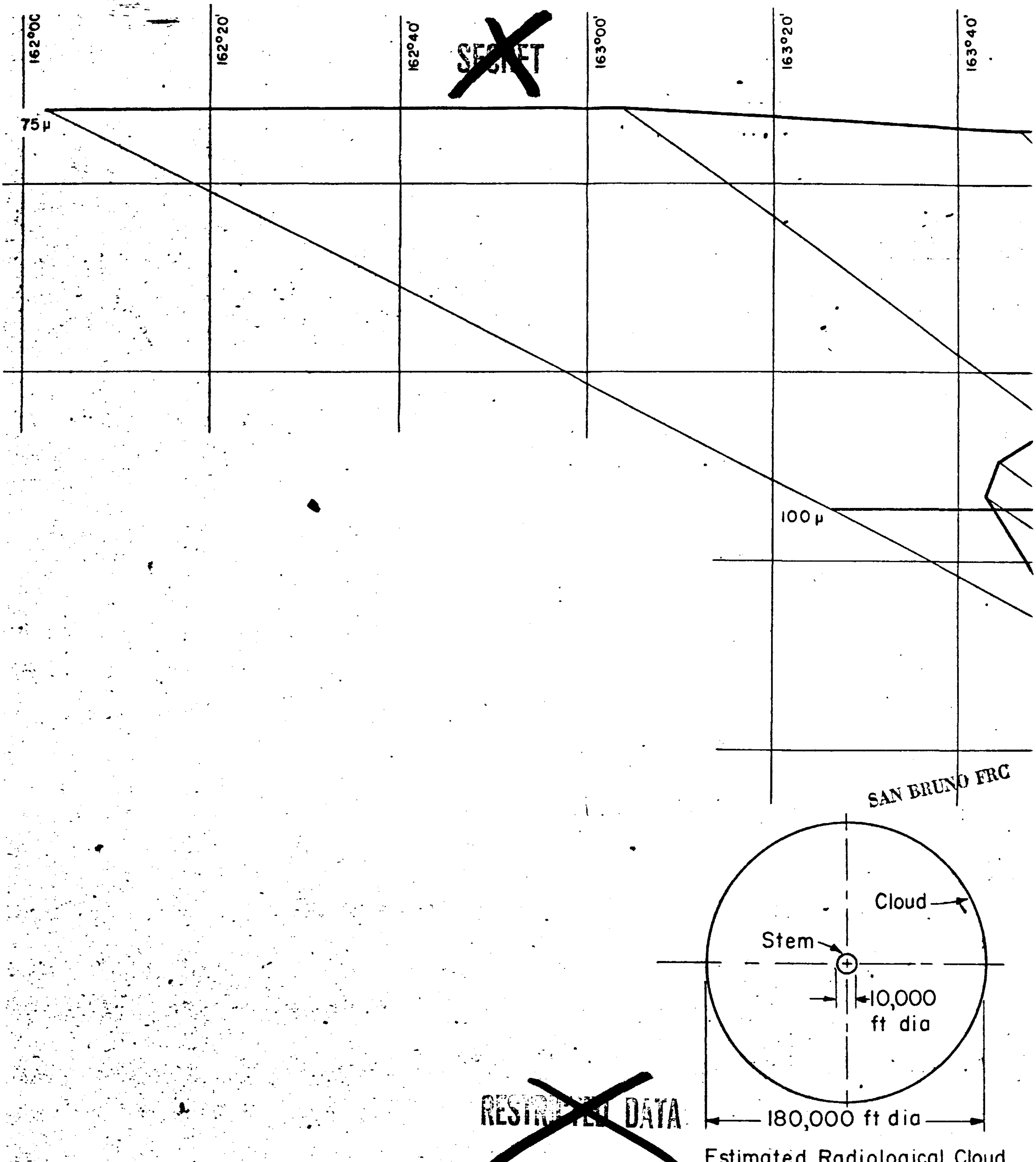
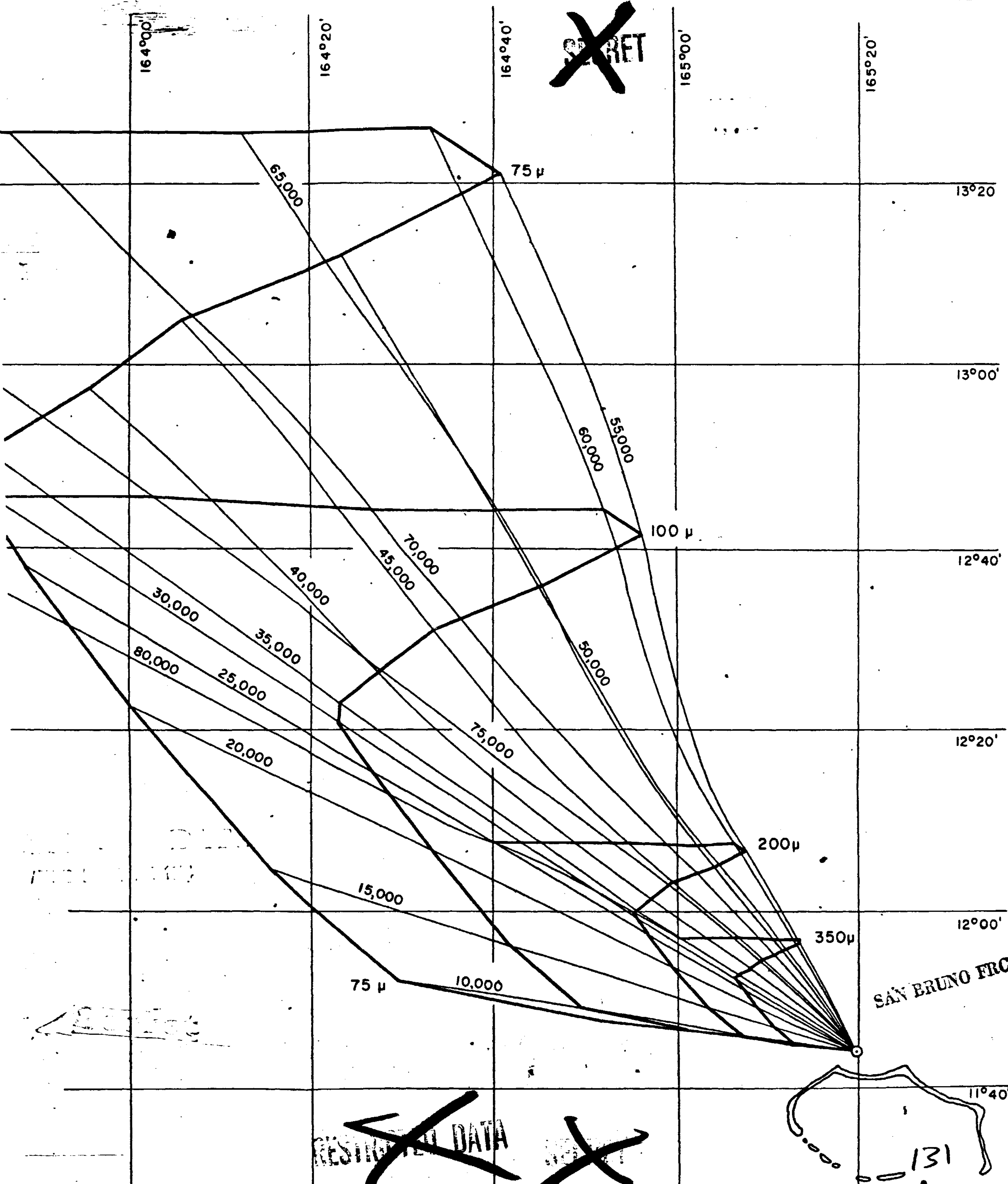


Figure 3.29 Cherokee Particle Fall Plot


164°00'
164°20'
164°40'
165°00'
165°20'
13°20'
13°00'
12°40'
12°20'
12°00'
11°40'
75 μ
100 μ
200μ
350μ
75 μ
65,000
60,000
55,000
70,000
45,000
40,000
50,000
30,000
35,000
80,000
25,000
75,000
20,000
15,000
10,000

131

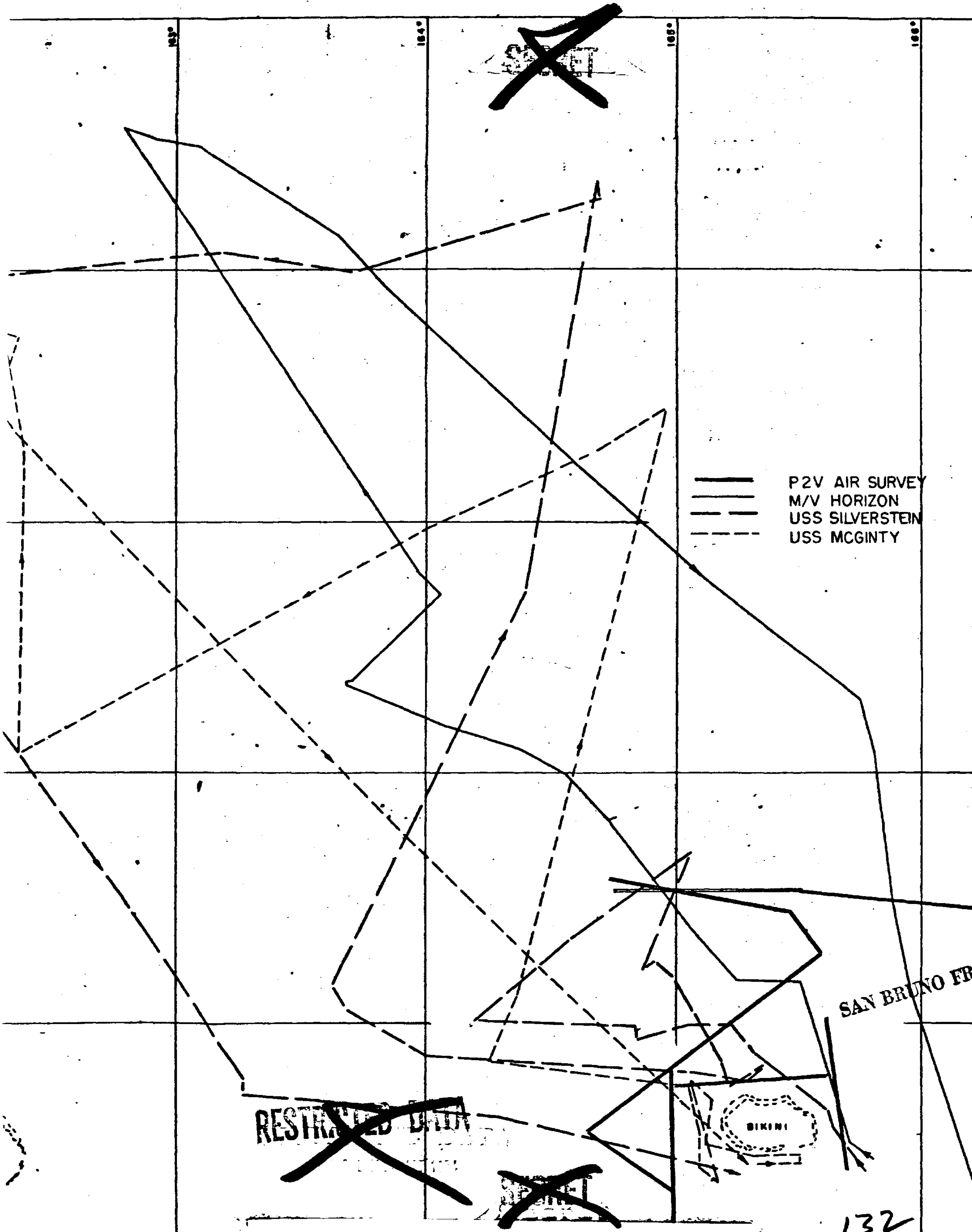


Figure 3.30 Ship and Aircraft Paths for Cherokee Fallout Survey.

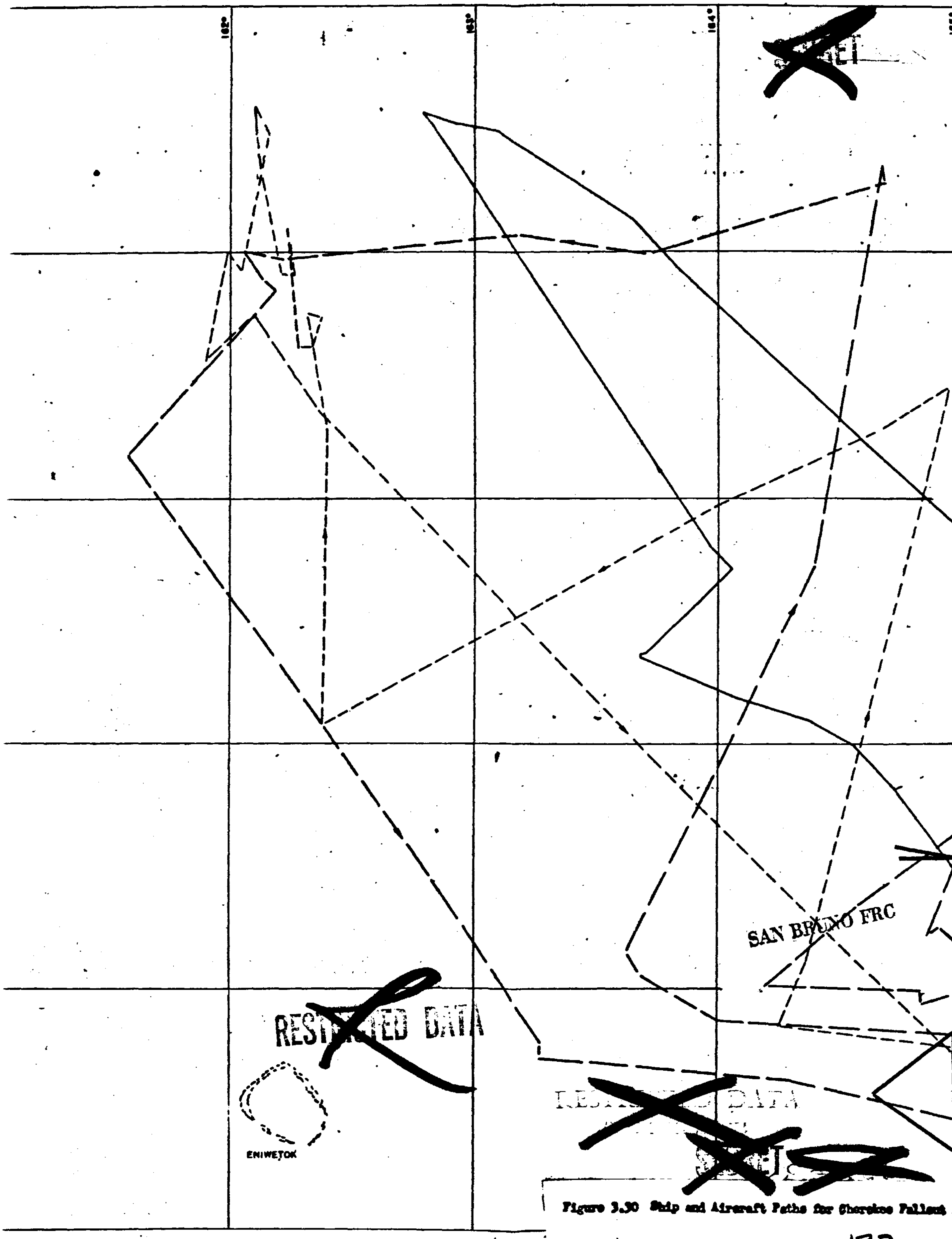
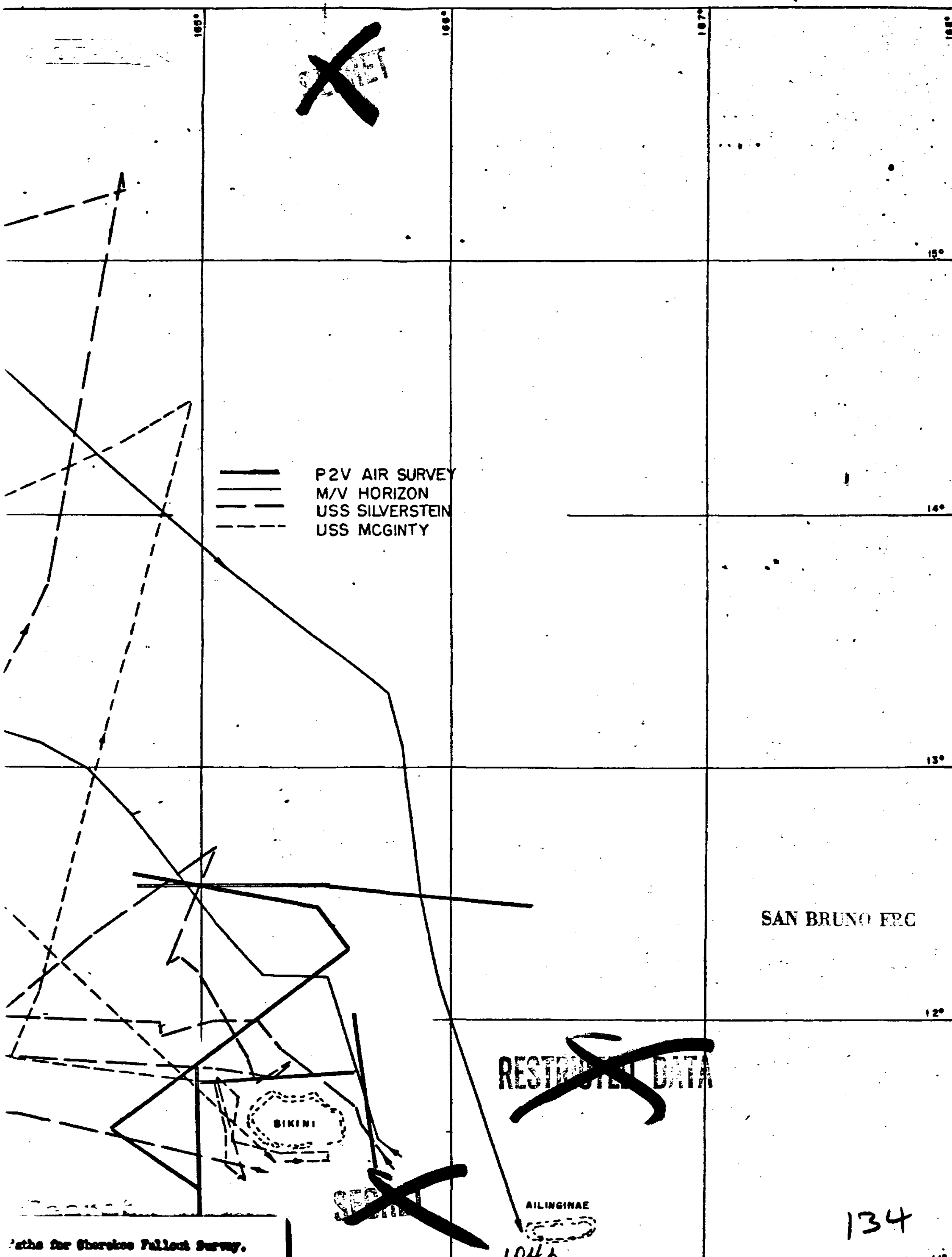


Figure 3.30 Ship and Aircraft Paths for Cherokee Fallout



'aths for Cherokee Fallout Survey.

does not produce an appreciable density of fallout contamination.

3.2.2 Osage. The Osage device was detonated at a height of 680 feet over Site Yvonne at 1314M on 16 June 1956. The yield was measured to be [redacted] The only available data on radiation levels is from RadSafe surveys since no Program 2 fallout projects participated. The H+1 hour exposure rate at ground zero was measured to be about 16 r/hr. All other measurements could not be distinguished from the residual radiation from previous detonations.

3.3 WATER SURFACE BURSTS

3.3.1 Flathead.

3.3.1.1 Introduction. The Flathead Shot was fired on a barge located off Site Dog (see Figure 3.31) at 0626M on 12 June 1956. The yield was measured to be [redacted] The only large masses of material in the shot barge were steel (about 260 tons) and coral (about 230 tons). It would not be surprising if a small but measurable amount of these materials was found in the fallout collectors since a calculation assuming that there is no fractionation, namely that the fission product activity is proportional to the total mass of barge material deposited, predicts that about 3 mg each of iron and coral should be deposited per square foot of surface at a location where the exposure rate extrapolated to H+1 hour is 100 r/hr.

As shown in Figure 3.31, the Flathead Shot barge was anchored in approximately 114 feet of water. Therefore, the shot actually approximated a surface water burst in a deep harbor. In addition to furnishing fallout data on these particular shot conditions, it is to be hoped that

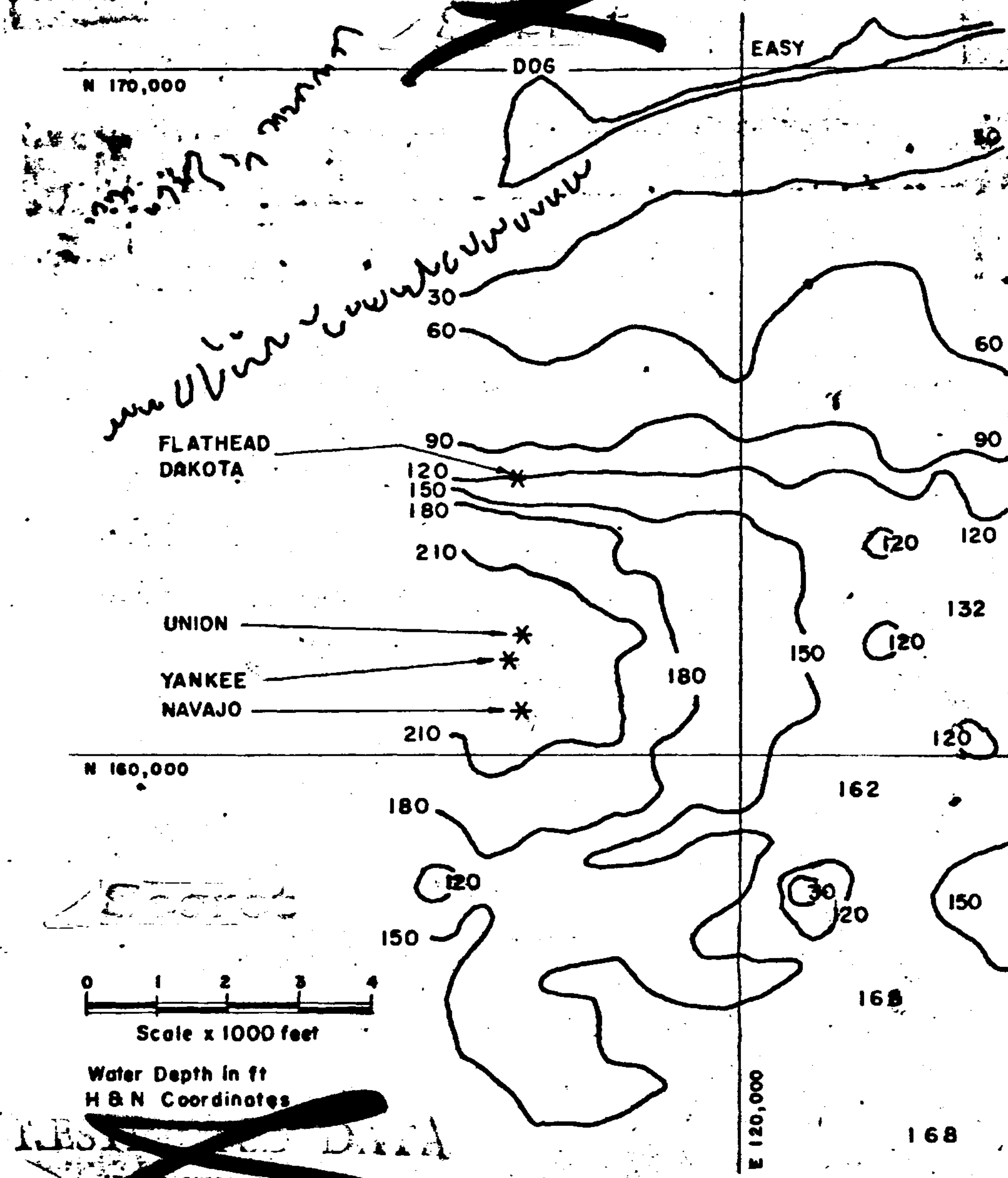


Figure 3.31 Bikini Lagoon Water Depths Prior to REDWING in the Primary Barge Shot Location.

a more complete understanding of the mechanisms involved can be gleaned from the data so that it can be applied to other burst conditions.

3.3.1.2 Particle Fall Plot. The Flathead particle fall plot is illustrated in Figure 3.32. The unusual appearance of the upper height lines, which come back toward ground zero for the smaller particles, is a reflection of the severe time changes of the wind profile. The fallout times were characterized by a rapidly changing wind situation during which cyclonic or anticyclonic centers moved through the fallout area at most altitudes.

For a review of the limitations and the interpretation of this plot, the discussion in Section 3.1.1.3 should be consulted.

3.3.1.3 Characterization of Fallout Material. The fallout material differed in appearance greatly from that of the land surface bursts. At the close-in stations, most of the activity was associated with a "mud." This material was collected with difficulty, remained quite wet for a period of a day, and was subsequently removed from the collecting surfaces with even more difficulty. It was found to consist of fine coral particles, NaCl, and sizeable amounts of FeO_3.

The more distant fallout consisted mainly of a salty slurry. The effective droplet diameter at the YAG 40 position was 100-200 microns, and these consisted of 80-90 percent NaCl. The activity was, in general, associated with a very small (5-10 micron) particle inside the droplet.

3.3.1.4 Land Equivalent Distribution of Fallout Activity. The data for the fallout radiation plot of Figure 3.33 have been derived from the same sources as those enumerated in Section 3.1.1.5. However, the fact

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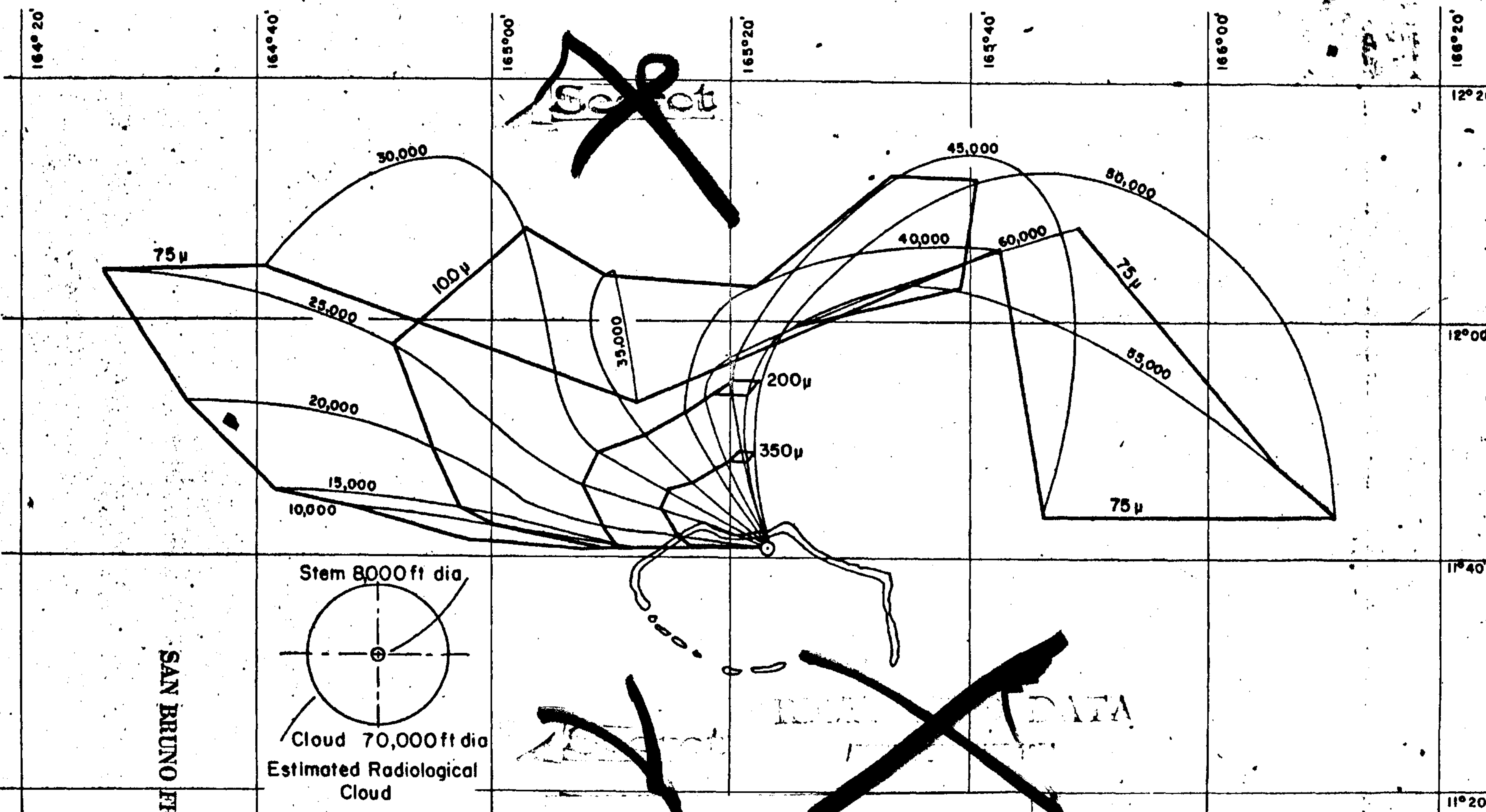

Figure 3.32 Flathead Particle Fall Plot.

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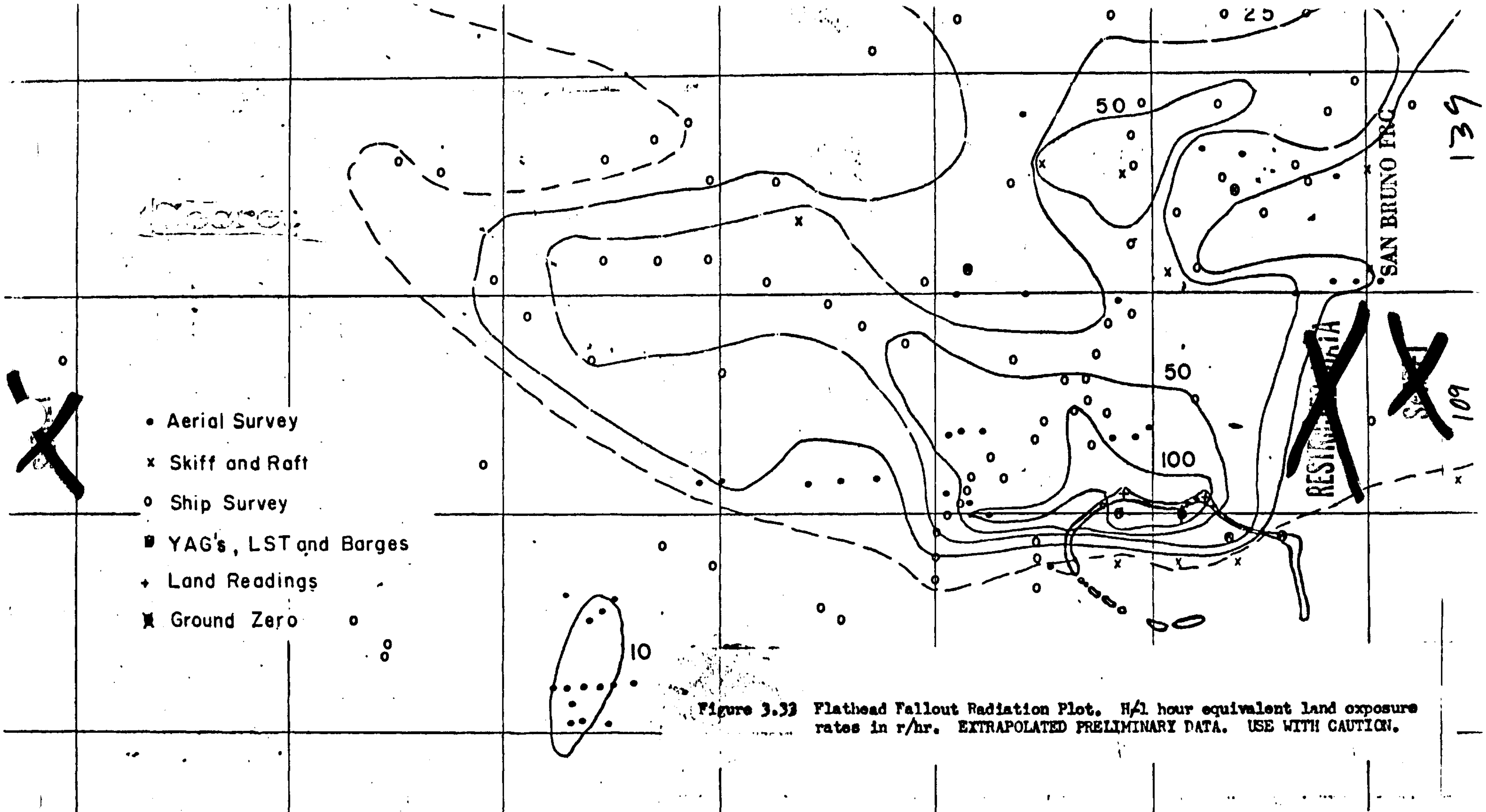
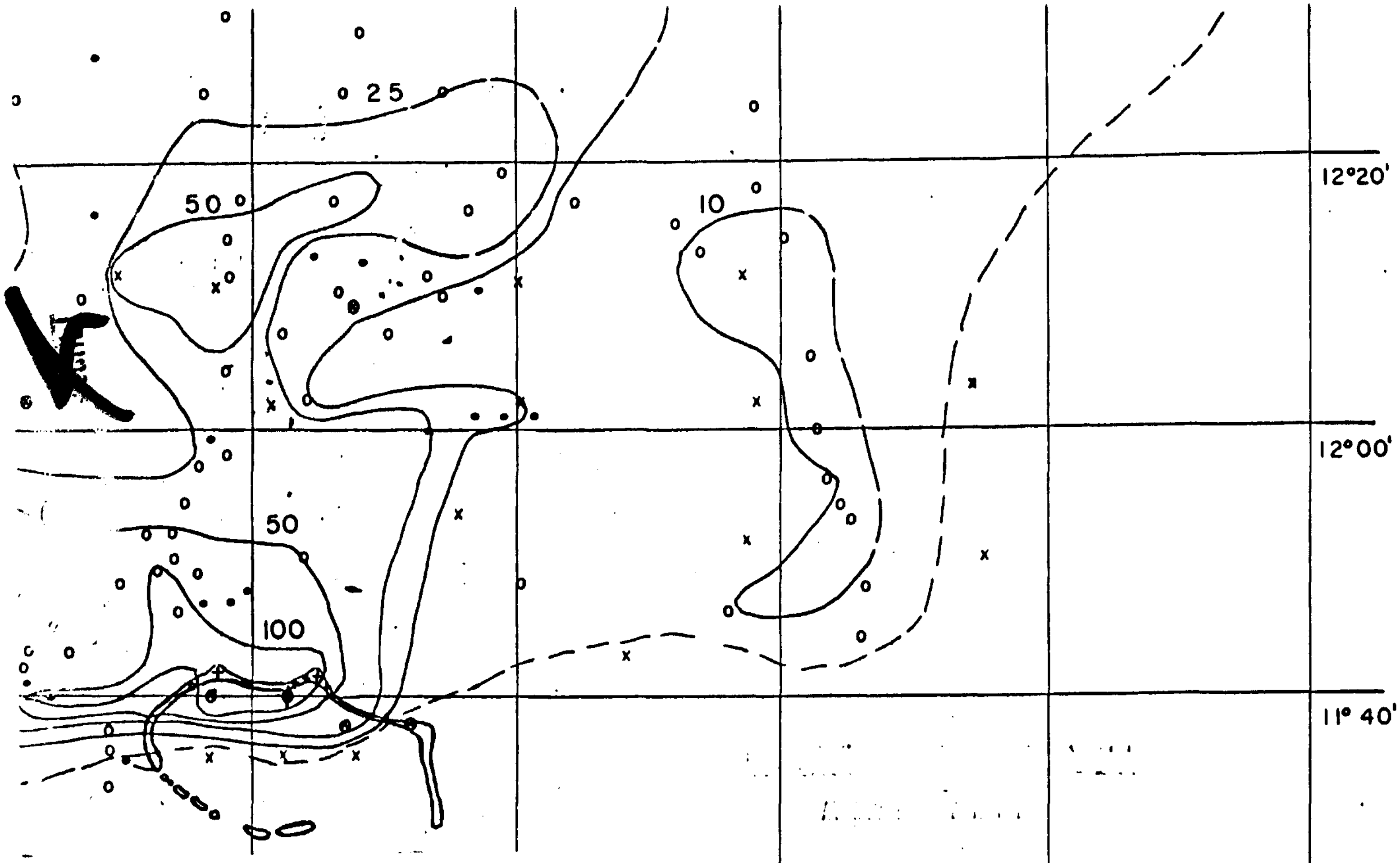


Figure 3.33 Flathead Fallout Radiation Plot. H+1 hour equivalent land exposure rates in r/hr. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.



Radiation Plot. H/1 hour equivalent land exposure
EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.

11° 20'

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109a

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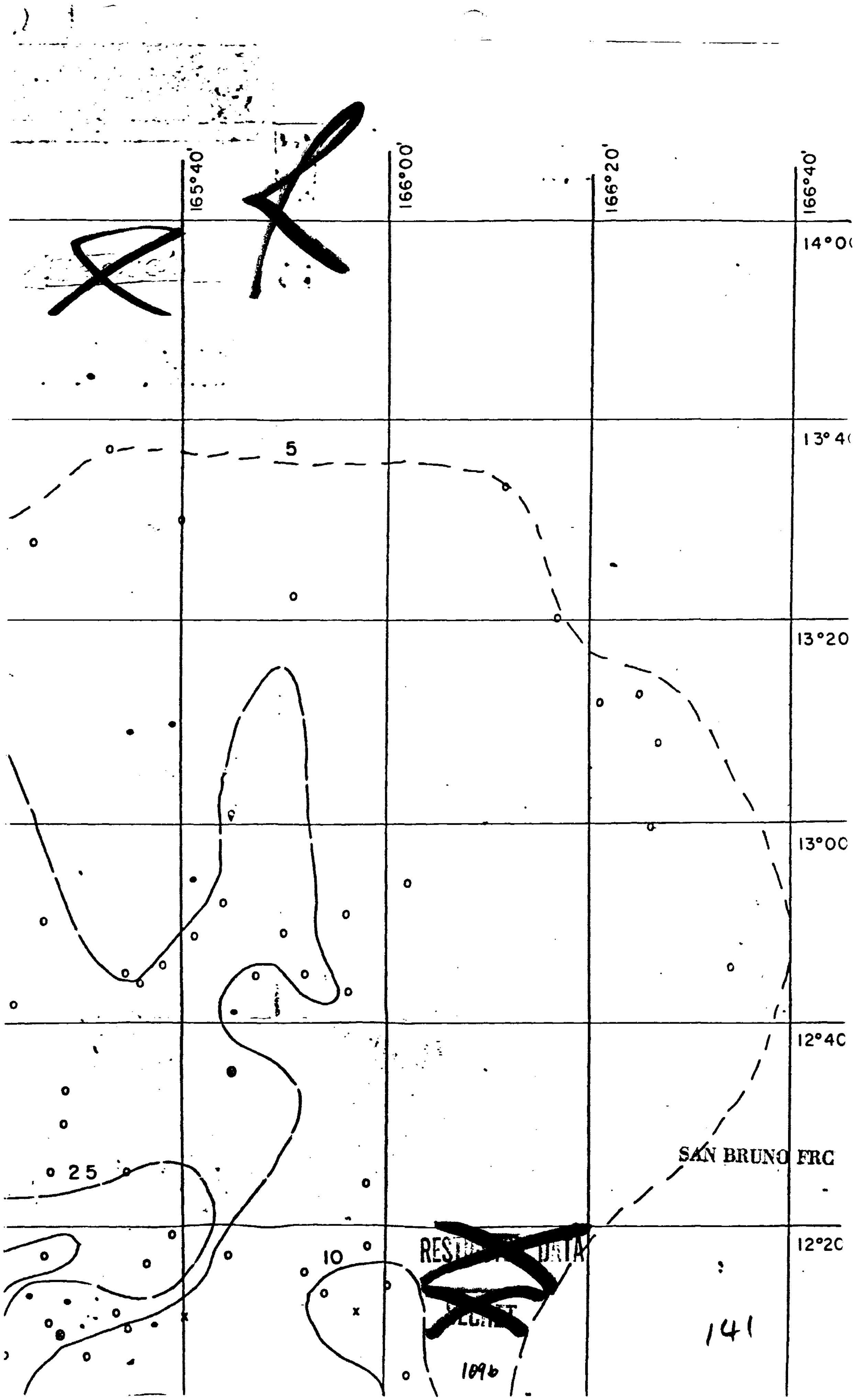
165°40'
166°00'
166°20'
166°40'
14°0
13°4
13°20
13°00
12°40
12°20
5
25
10
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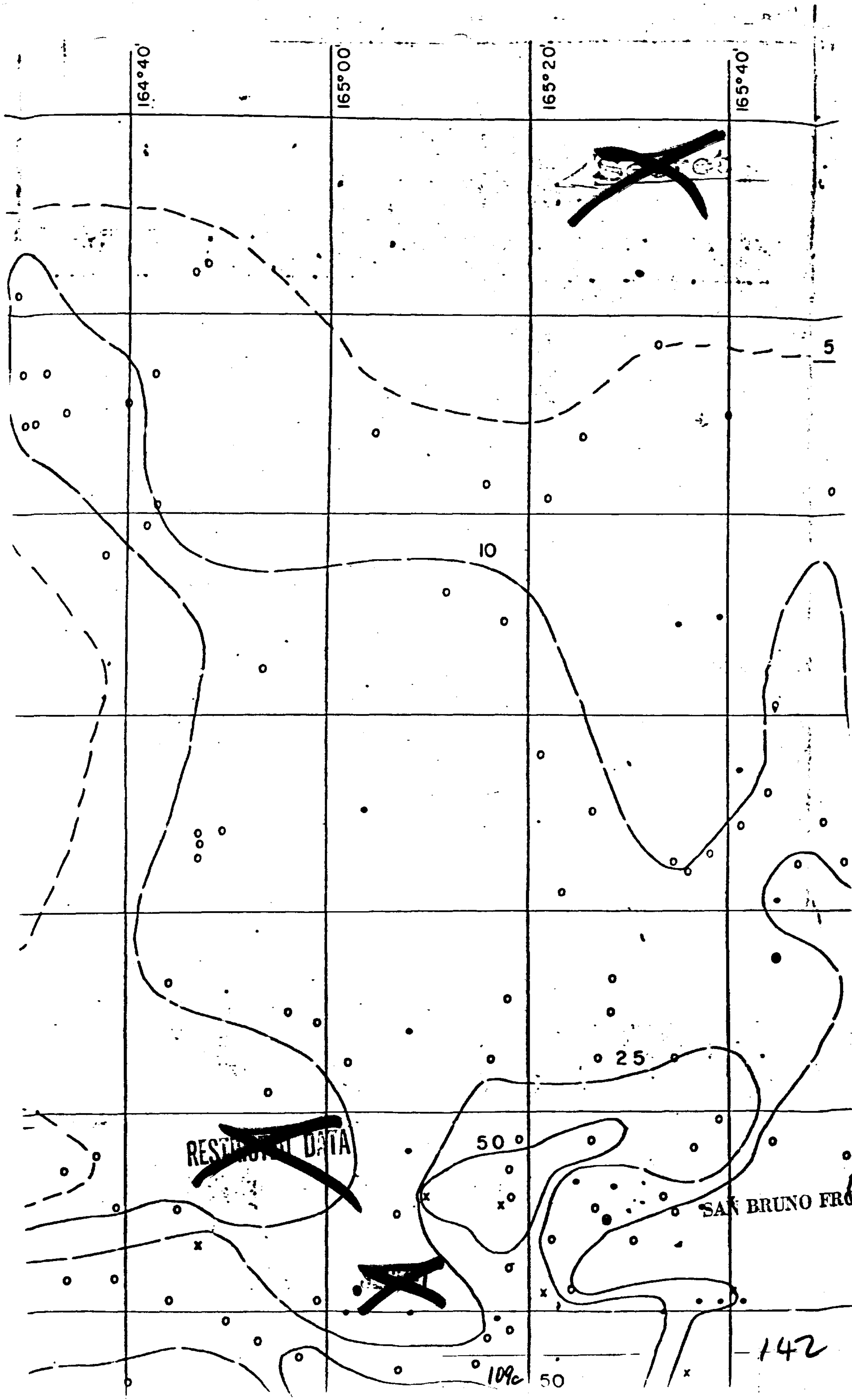
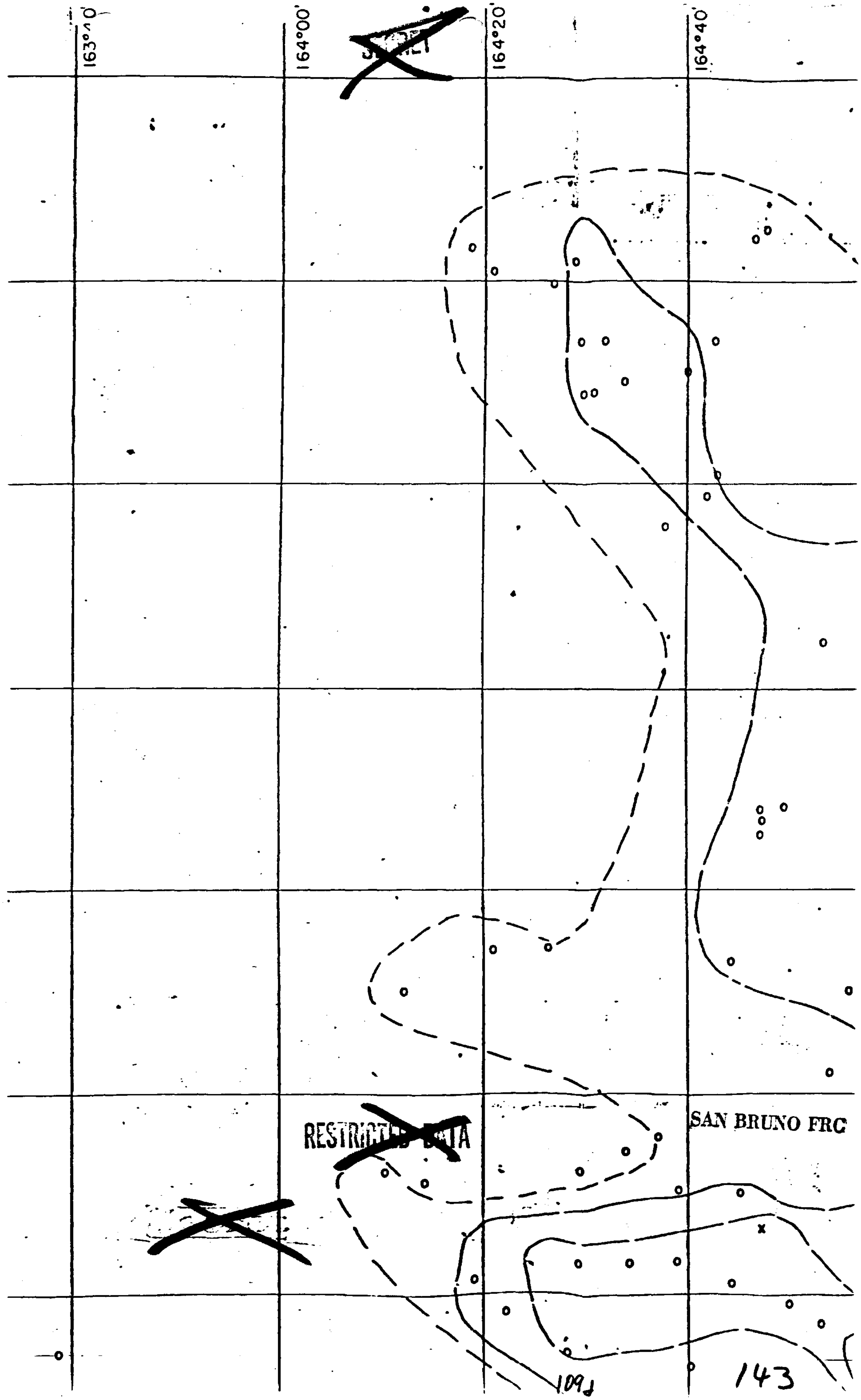
REST
DATA
1096


164°40'
165°00'
165°20'
165°40'
5
10
25
50
50
109c


164°00'
164°20'
164°40'
RESTRICTED DATA
SAN BRUNO FRC

that the activity from this water surface burst was generally associated with liquid or very small particulate enclosed by liquid droplets implies that the water survey readings can be used with more confidence. In this case, most of the activity would be distributed in depth by the mixing of the ocean water and not by the direct influence of gravity on particulate matter. Since there probably was no activity associated with sizeable solid particles, ~~therefore~~ all the activity that was deposited on the ocean surface was accessible to the probe readings. An example of the readings on a typical probe cast is illustrated in Figure 3.34.

The problem of background radiation levels can not be considered in this report. Suffice it to say that low background readings extrapolated for assumed decay during the long periods of the survey, can have appreciable influence on the measured contour values. The data as presently reduced have not been corrected for such effects. An illustration of this problem is furnished by a survey that was performed subsequent to the Flathead event, but just prior to Navajo. It indicated that a region west of Bikini Atoll and curving toward the south was contaminated by water which probably originated near the Zuni and Flathead craters (see Figure 3.43). It is therefore quite likely that the finger-like region of contamination indicated in this area by the Flathead fallout surveys was not caused by fallout, but was due to contaminated effluent from the Bikini Lagoon.

The observations by Project 2.62 probe casts, which measured vertical radiation profiles similar to that illustrated in Figure 3.34, ~~were~~ indicated that the effective depth of penetration for the Flathead fallout was about

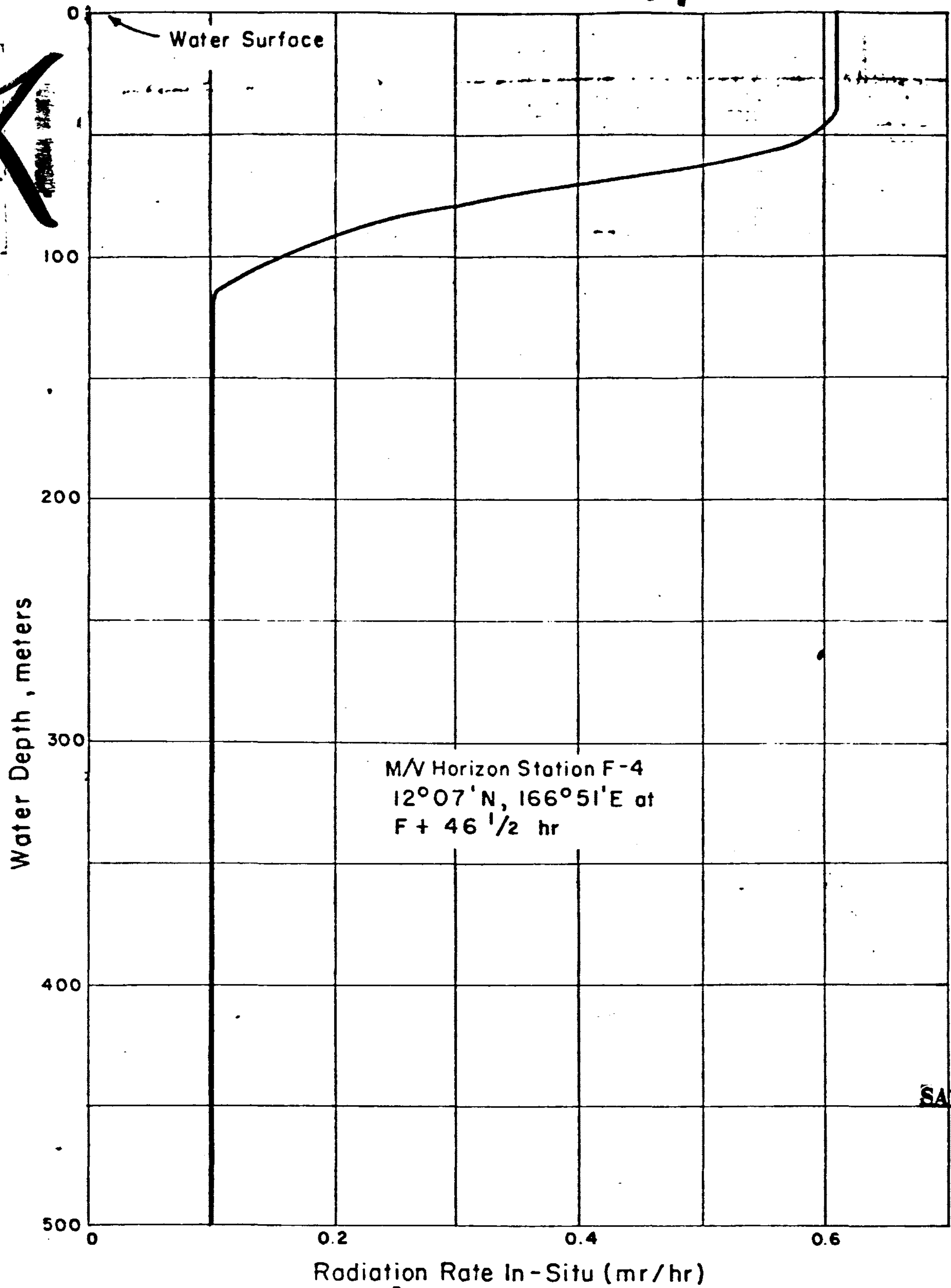


Fig 3.34

Figure 3.34 Typical Exposure Rate versus Depth Profile. This was r[illegible] northeast of Flathead ground zero at 0430 on 14 June 19[illegible]

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36 meters at 10 hours after the detonation, increased linearly to 80 meters at 34 hours, and thenceforth remained essentially constant. The decay exponent measured by the probe in the decay tank aboard the M/V Horizon was 1.05. These observed values of the depth of penetration and decay exponent were used in the reduction of the Project 2.62 water survey and Project 2.64 aerial survey data. The water motion corrections discussed in Section 3.1.1.5 were also applied to this data.

3.3.1.5 Central Time of Arrival Contours. The calculated central time of arrival contours, as well as the observed data points, are presented in Figure 3.35. The interpretation of this data has been discussed in Section 3.1.1.6.

3.3.1.6 Ten Hour Exposure Contours. The ten hour exposure contours for Flathead constructed as discussed in Section 3.1.1.7 are presented in Figure 3.36. The corrected exposure data points are also indicated in this figure.

3.3.1.7 Cross Decay Exponent. The Np^{239} capture to fission ratio reported for the Flathead event was 0.31. The decay exponents measured under various conditions are summarized in Table 3.4.

3.3.2 Navajo.

3.3.2.1 Introduction. The Navajo device was fired on a barge moored off Site Dog (Figure 3.31) in water about 215 feet deep, at 0556M on 11 July 1956. The yield of the weapon was measured to be [redacted]

[redacted] This device was the [redacted] of the REDWING devices and therefore provided an excellent opportunity to document the fallout fairly near the shot point without exposing the

Figure 3.35 Flathead Central Time of Arrival Plot. Times in hours.

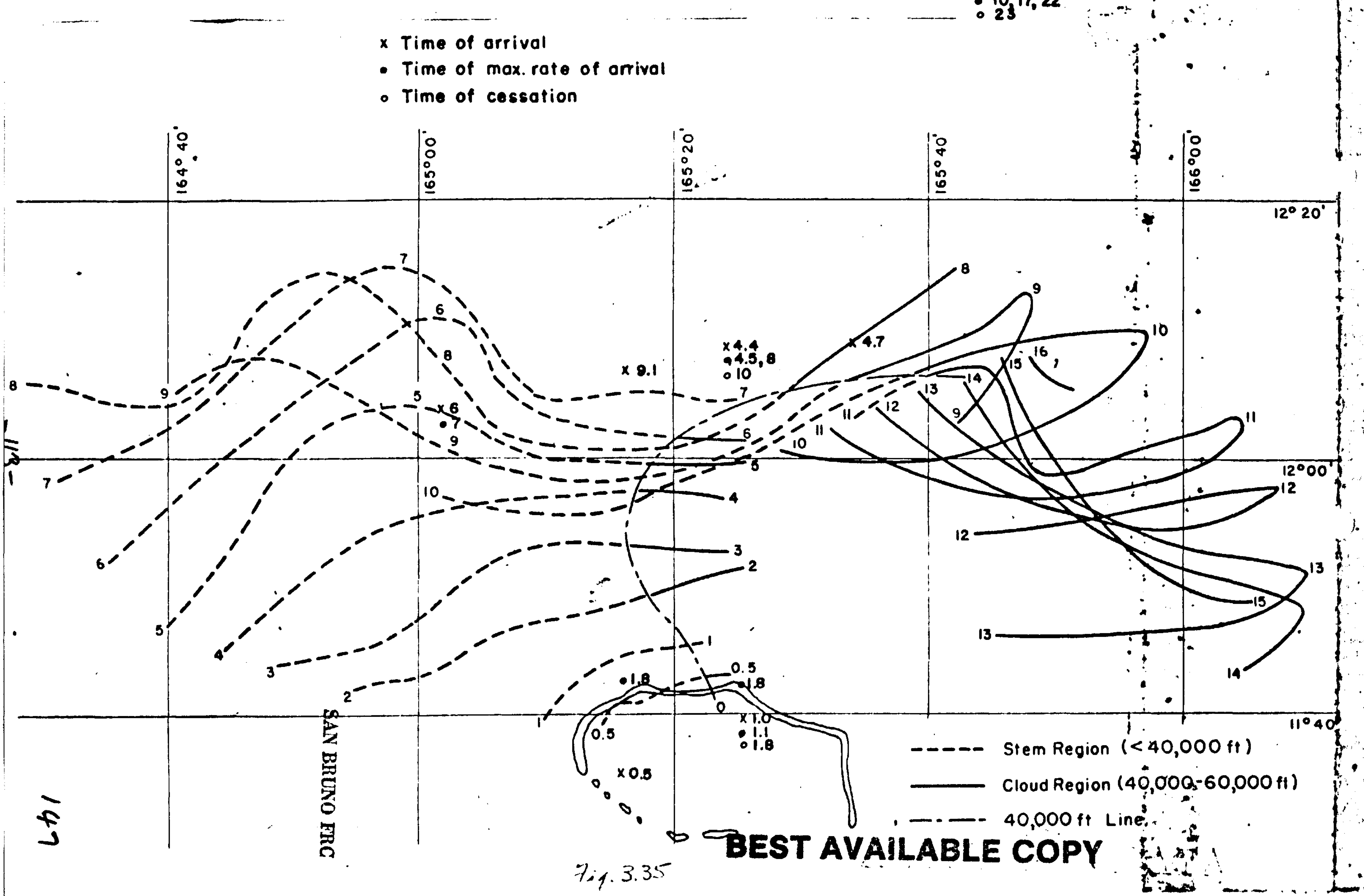

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Fig. 3.35

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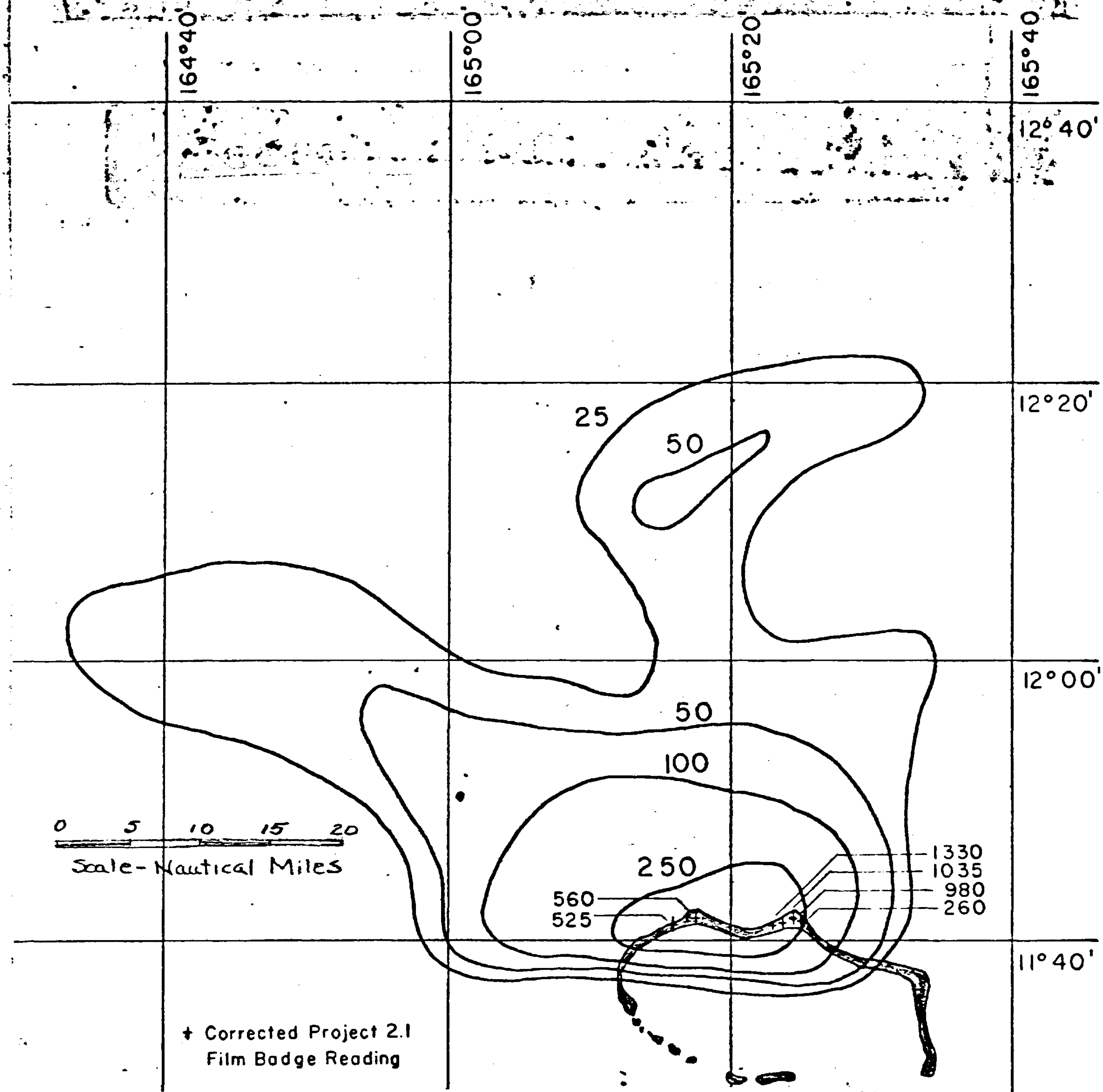

Figure 3.36 Flathead Ten Hour Exposure Contours.

Exposure ... EXTRAPOLATED PRELIMINARY DATA USE WITH CAUTION

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TABLE 3.4 Cross Decay Exponents for Flathead

	Time (Hours)	5–20	20–50	50–200
Decay Exponent	Gamma Photons*	–	0.6	1.0
	Gamma Exposure Rate	–	1.2	1.2
	Beta dis/min	–	0.9	1.0
	Field Gamma Exposure Rate	–	1.0	–
	Gamma Exposure Rate in Water	–	~~1.13~~ 1.05	–

*YAG-40 Samples Only

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[redacted]

operational personnel to excessive radiation.

To compare radiation readings from Navajo with those DELETED

DELETED

The wind pattern which existed at and after shot time was characterised by very weak winds at all altitudes up to 55,000 feet, and hence much of the fallout pattern was concentrated quite close to Bikini Atoll. Nevertheless, the observed radiation intensities were not excessive. However, if the Navajo weapon's yield had been predominantly from fission reactions, the exposure rates in the Dog-George complex would have been higher than 1000 r/hr at H+1 hour and operational difficulties would have resulted for all agencies needing access to those sites.

The Navajo device also provided the opportunity to measure the effectiveness of "salting" by a tracer experiment. About [redacted] each of [redacted] were inserted amidst the thermonuclear fuel and the collected fallout material was analyzed for the activation products resulting from neutron capture reactions. However, this detailed radiochemical analysis was performed in the home laboratories of Projects 2.63 and 2.65 and therefore the results were not available at the time of writing of this report.

The contribution to the fallout radiation from activity induced in the surrounding material of the shot point could also be determined.

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DELETED the chance of detecting induced activity in the presence of the fission product activity was increased. In particular, activity from Na^{24} produced in the salt water was expected to be observed even though

[redacted]

... half life is only 15 hours. Again this analysis was performed in the home laboratories and the results were not available for this report.

The Navajo shot barge included about 250 tons of iron and 200 tons of coral, but this material was spread over a much larger area by the [redacted] compared with Flathead. Since [redacted] the association of exposure rate and mass of material is the same (i.e., about 3 mg each of iron and coral per square foot where H/1 exposure rate is 100 r/hr), but the levels of the radiation fields from Navajo were much lower than those from Flathead.

3.3.2.2 Distribution of Activity in the Stabilized Cloud and Stem. Since the previous shots, Cherokee and Zuni, had yielded reasonably good data on the distribution of activity in the nuclear cloud, but no data on the stem, it was decided to allocate the entire six rockets of the H/7 minute salvo to the Navajo stem. The rockets were all aimed at an elevation corresponding to a penetration height of about 26,000 feet and were spread in azimuth to cover all possible directions of motion of the stem to be expected from the local wind conditions.

Figure 3.37 presents the cross sections of the stem in the plane of the trajectories of rockets 2A, 3A, and 4A. Figure 3.38 is a view of the stem looking along the trajectories indicating the points at which the rockets pierced the center plane of the stem at 26,000 feet. Only two of the rockets indicated radiation; Numbers 2A and 3A. These exposure rates were less than 50 r/hr, and could not be accurately measured with the equipment available in the field. Rocket 2A received a total exposure of about 0.08 r between 13 and 28 seconds after launch time, and rocket 3A received a total exposure of about 0.24 r between 11 and 41 seconds

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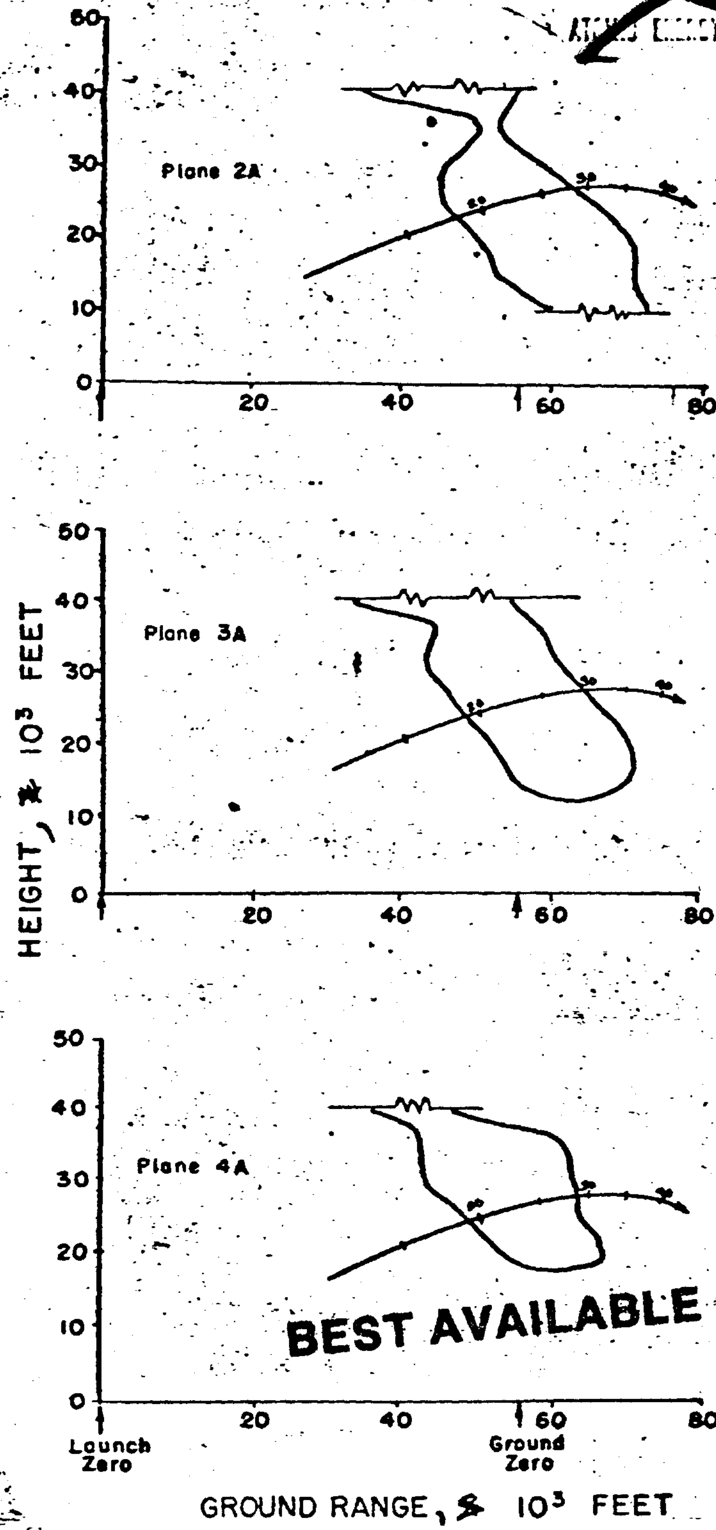

Figure 3.37 Navajo Stem at H+7 Minutes Showing Planes Through Three Rocket Trajectories. Numbers along trajectories are time in seconds from launch time.

...ter launch time. ~~Inspection of the positioning information in Figures 3.37 and 3.38 then~~ Preliminary analysis of the data indicates the following tentative conclusions:

a. The exposure rate in the stem is smaller than that in the cloud by at least a factor of 40.

b. The position of the stem checks with that predicted assuming the wind displaces it from zero time.

c. The radiological diameter of the stem is no larger than the visual diameter, and the indications are that the largest exposure rates are limited to a small fraction of the stem volume.

The H+15 salvo was allocated to measuring the exposure rate in the nuclear cloud, but in addition was designed to yield data on the reproducibility of the detector readings. Only three trajectories were chosen and two rockets were fired along each trajectory. Comparison of the readings from the one pair of rockets of which both yielded preliminary data indicated that the readings were reproducible within about 20%. The final reduction of the data will probably show the reproducibility to be better than this number.

The data for the three trajectories is presented in Figure 3.39 and the location of the plane of these trajectories through the cloud is illustrated in Figure 3.40.

The Project 2.66 manned aircraft penetrations of the stem of the Navajo mushroom were performed as soon as the Project 2.61 rockets were out of the air. The results of these penetrations, extrapolated back to H+15 minutes using a $t^{-2.0}$ decay relationship, are also presented in Figure 3.39.

The mushroom size which was used in Figures 3.39 and 3.40 was taken from a H+8 minute photograph. While there is some cloud expansion from the time

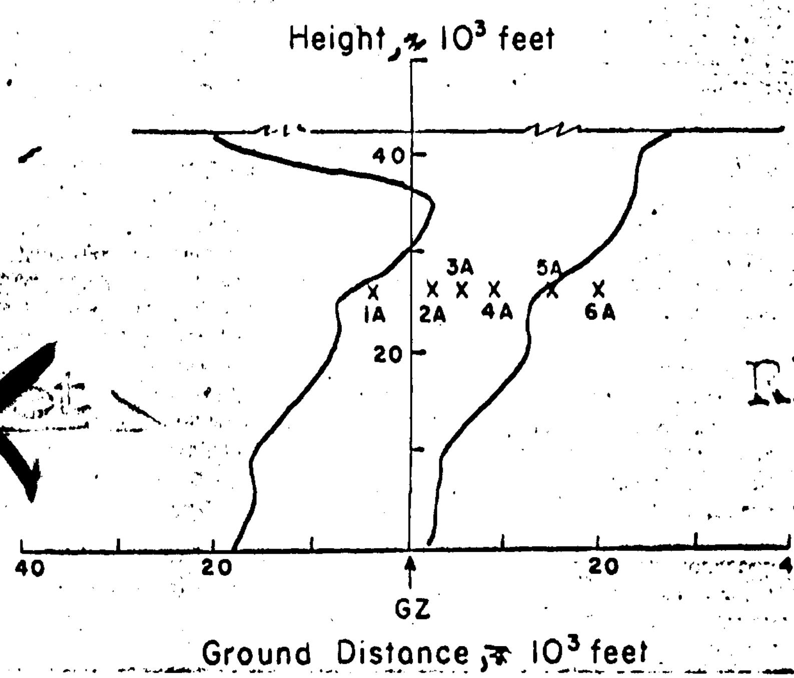

Figure 3.38 Navajo Stem at H+7 Minutes Showing Points (x) at Which Rockets Pierced Center Plane of Stem.

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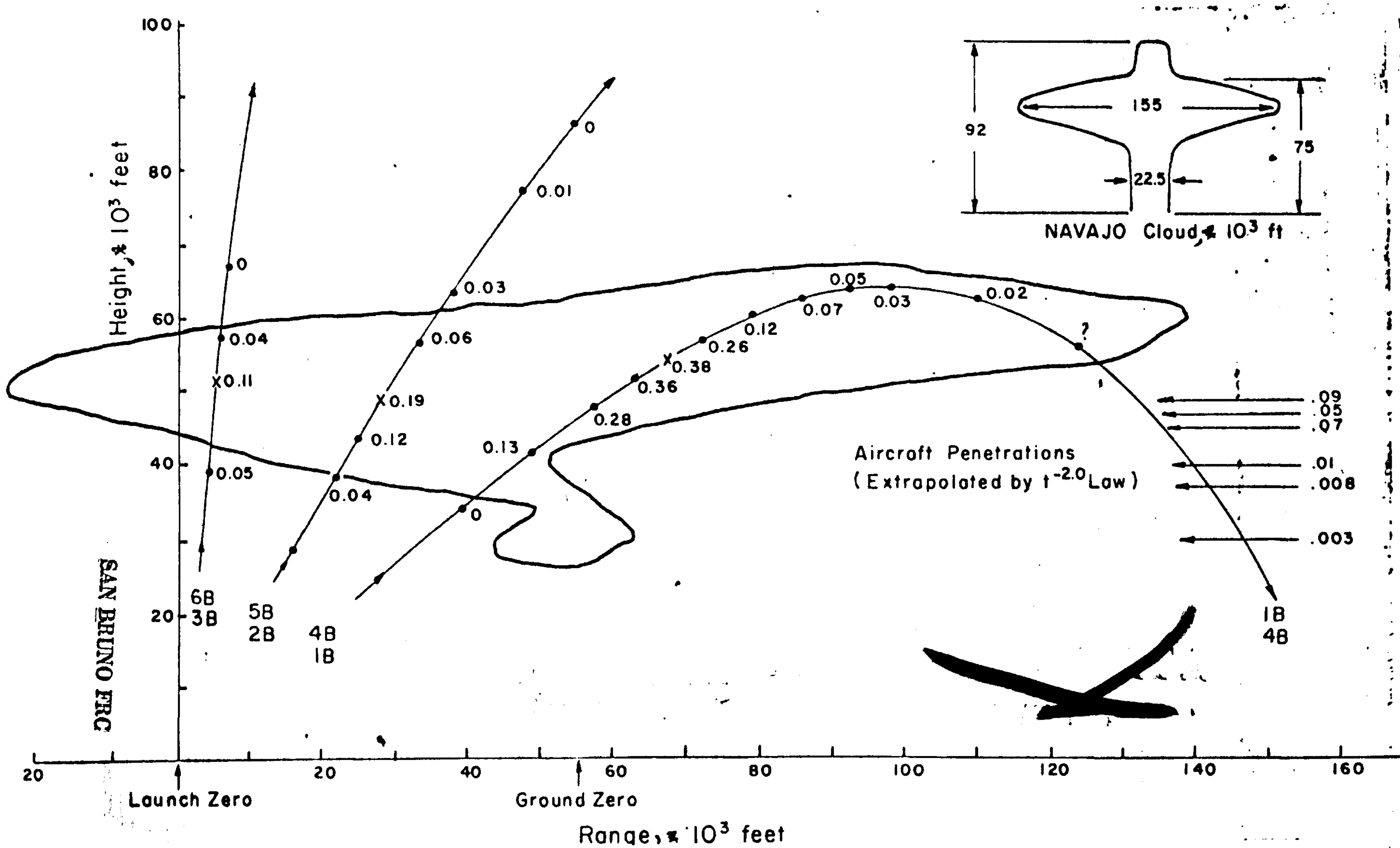

Figure 3.39 Navajo Cloud at H+15 Minutes in the Plane of the Rocket Trajectories. Readings along trajectories are corrected to sea level and are in units of 10^3 r/hr. Peak readings are denoted by an x.

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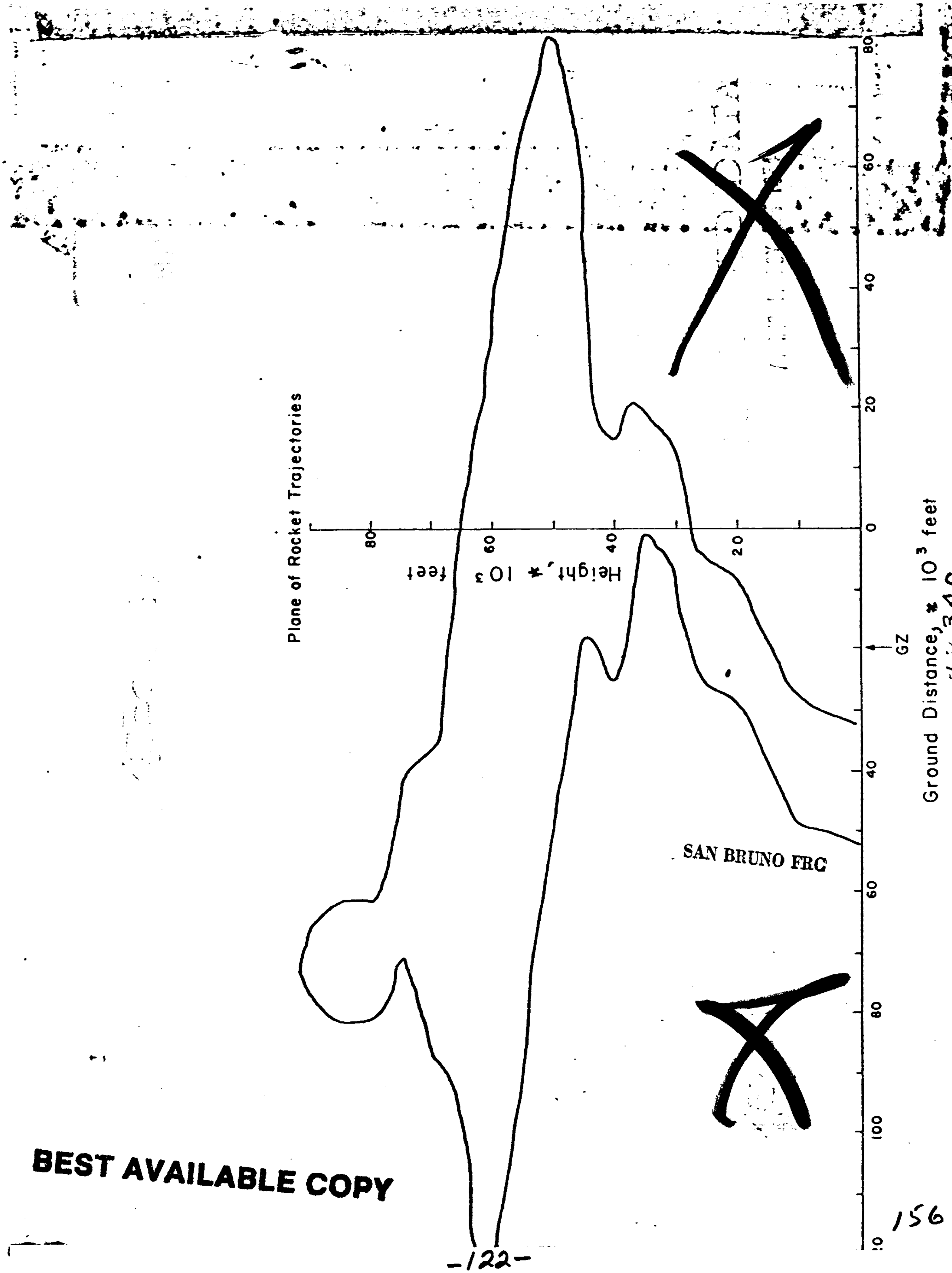

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Figure 3.40 Looking Along Plane of H/15 Minute Rockets Toward Navajo Cloud.

of the photograph to the time of the second salvo, this will not materially affect the general location of the rocket trajectories relative to the cloud. The fact that the assumed Navajo cloud is slightly smaller than the lower yield Cherokee-Zuni cloud is associated with the different methods used to derive the dimension. This inconsistency must be resolved by more complete analysis of photographic data.

3.3.2.3 Particle Fall Plot. The particle fall plot for the winds measured at and after shot time for the Navajo event is presented in Figure 3.41. This plot, which was constructed considering time and space variations of the wind profile, is characterized by the same weak winds that produced the small Flathead particle fall plot. Of course, the fact that the Navajo cloud was much higher, and hence was influenced more by the high altitude strong easterly winds, caused the actual fallout pattern to extend over a larger area than the Flathead pattern.

For a discussion of the interpretation and limitations of this plot, Section 3.1.1.3 should be consulted.

3.3.2.4 Characterization of Fallout Material. The Navajo close-in fallout material, as well as that observed at the YAG-40, resembled the salt laden slurry observed at the YAG-40 after Flathead. By the time the samples from the land stations were recovered, 80-90% of the particulate was fine salt crystals. There was some $CaCO_3$ among the remaining material. No iron was detected.

3.3.2.5 Land Equivalent Distribution of Fallout Material. The consolidated radiation survey data are presented in Figure 3.42. The data have been derived from the same sources, and reduced by the same methods, as those

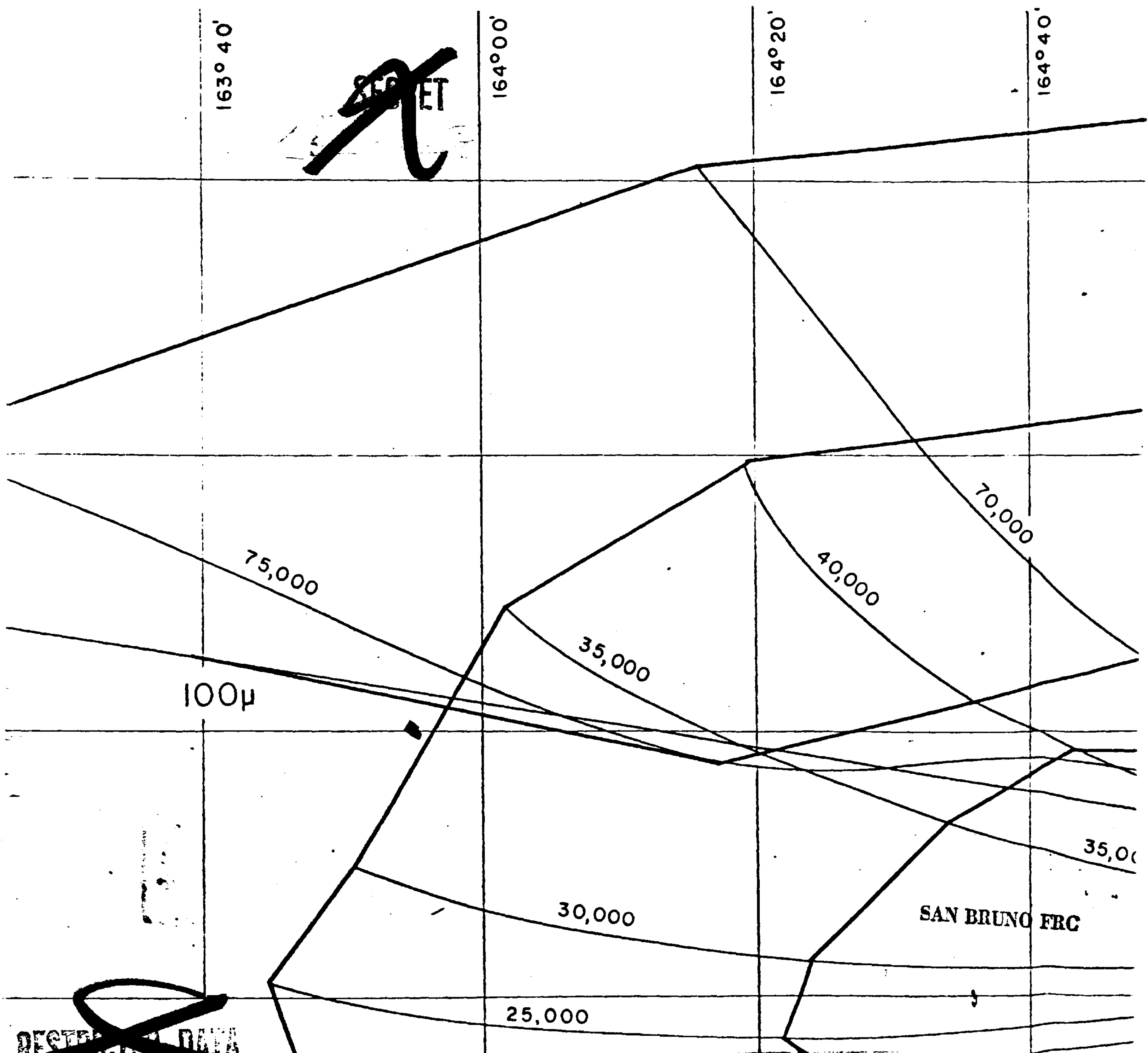
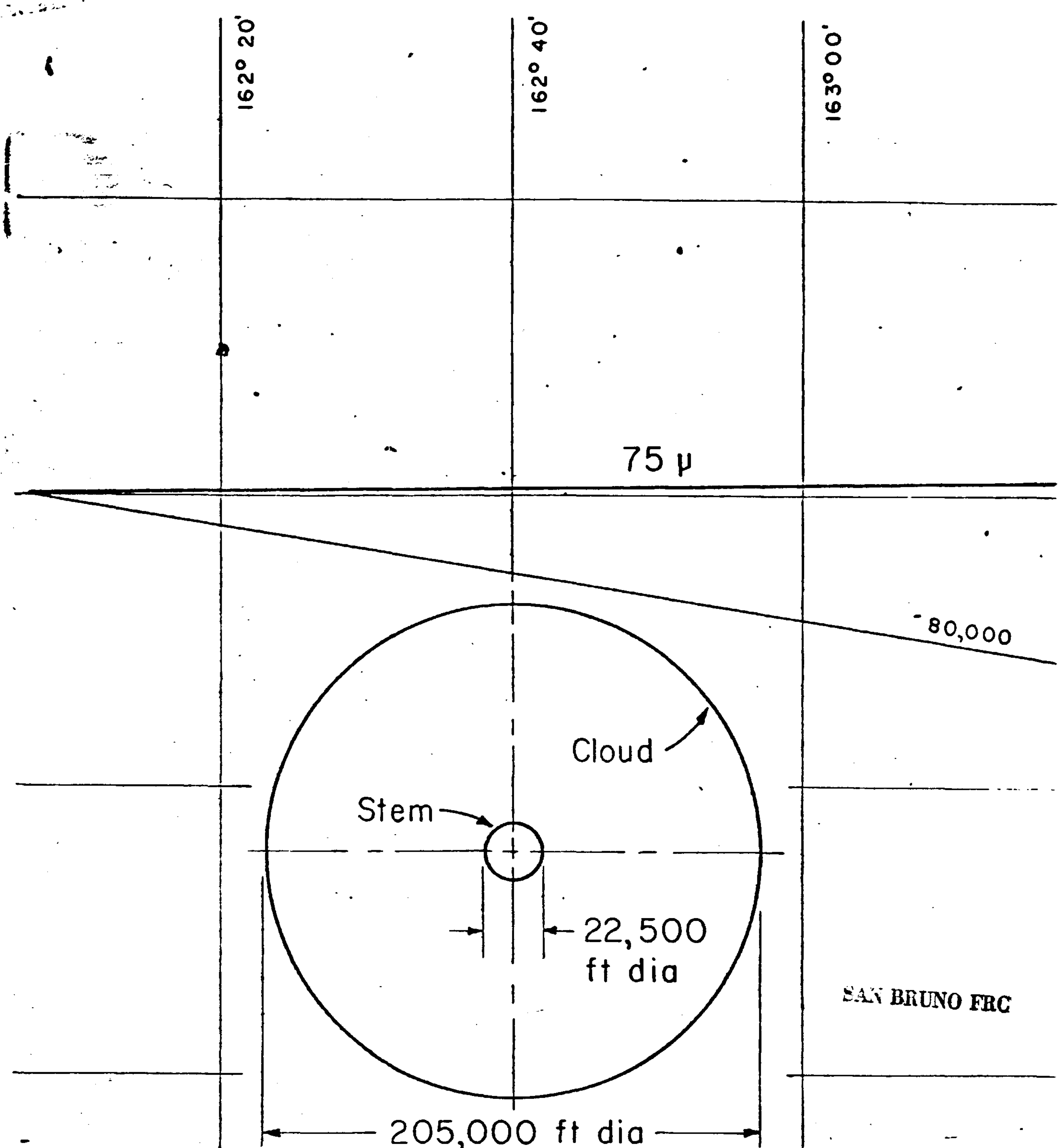
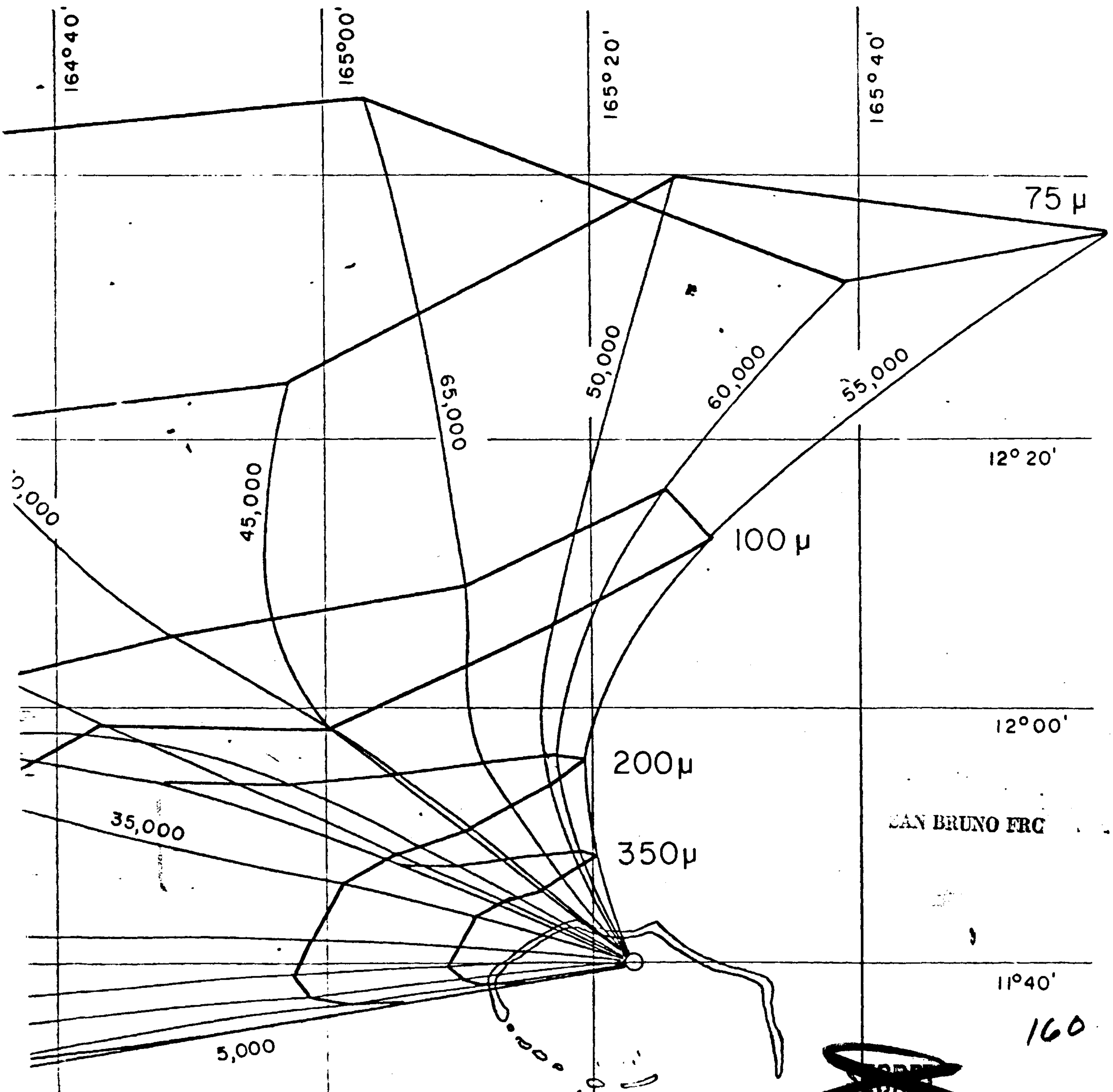


Figure 3.41 Navajo Particle Fall Plot.



Estimated Radiological Cloud

~~SECRET~~



164°40'
165°00'
165°20'
165°40'
75 μ
12° 20'
12°00'
11°40'
100 μ
200μ
350μ
65,000
50,000
60,000
55,000
45,000
,000
35,000
5,000
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124b

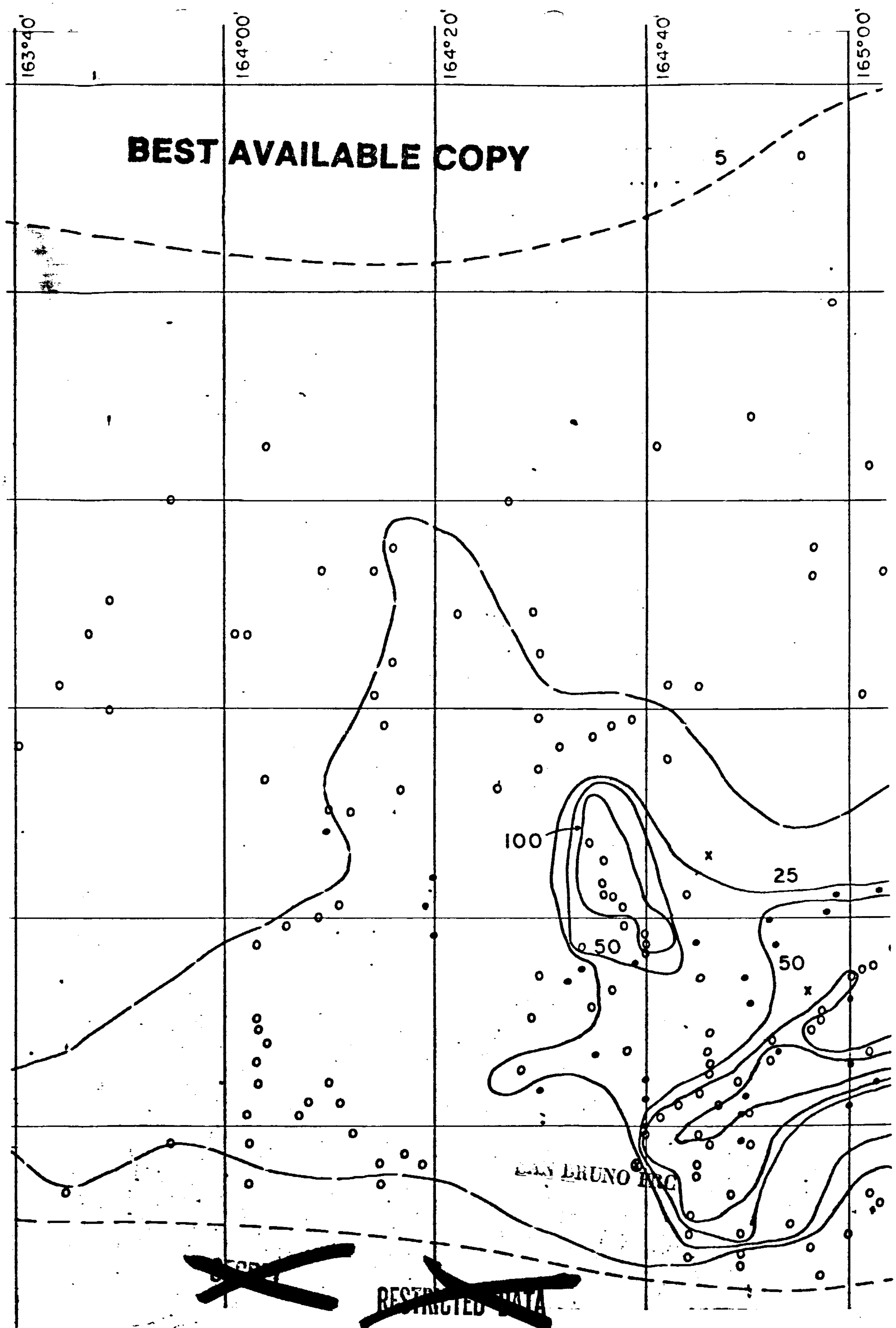

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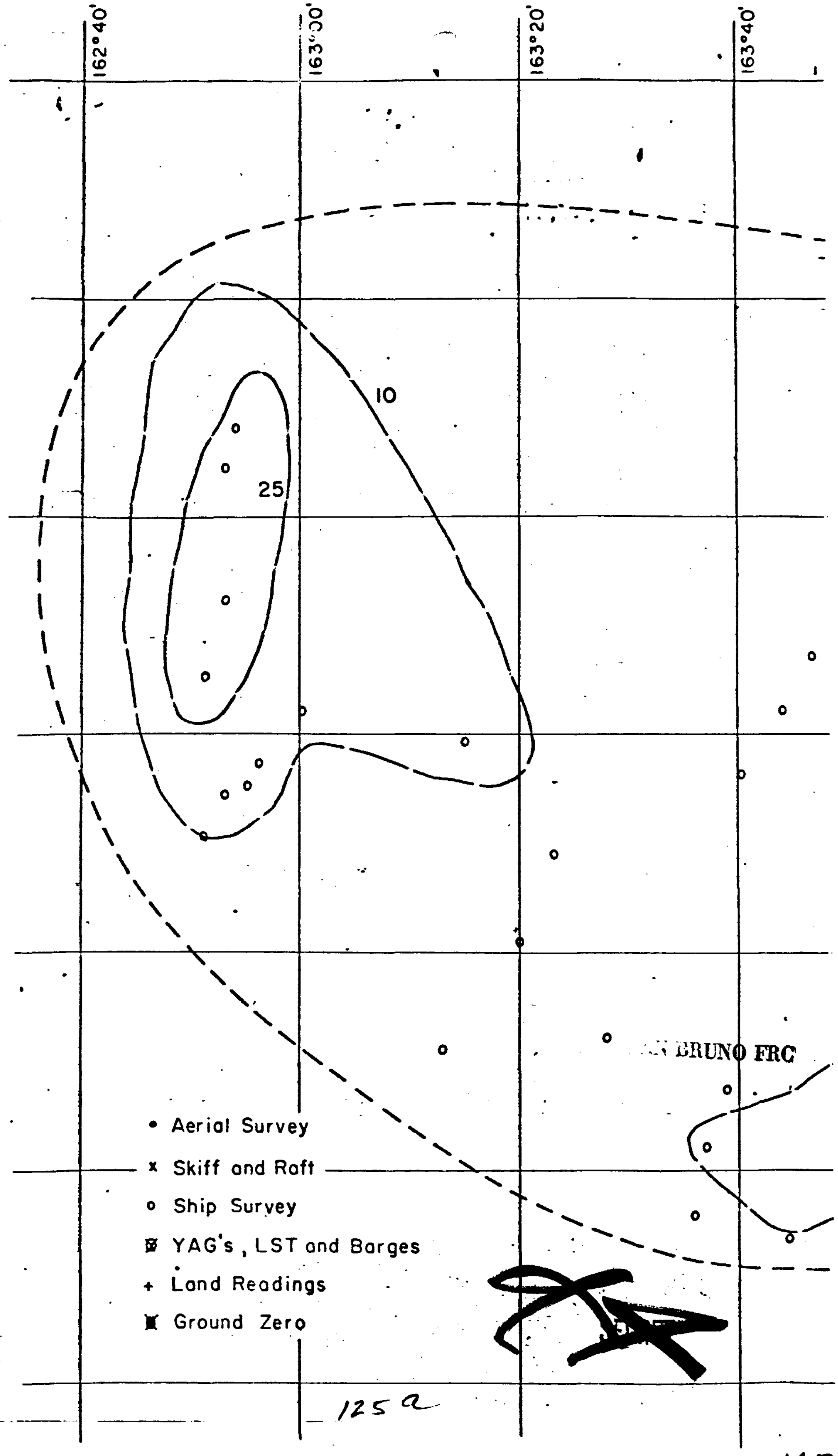
Figure 3.42 Navajo Fallout Radiation Plot. H/1 hour equivalent land exposure rates in r/hr. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.


162°40'
163°00'
163°20'
163°40'
10
25
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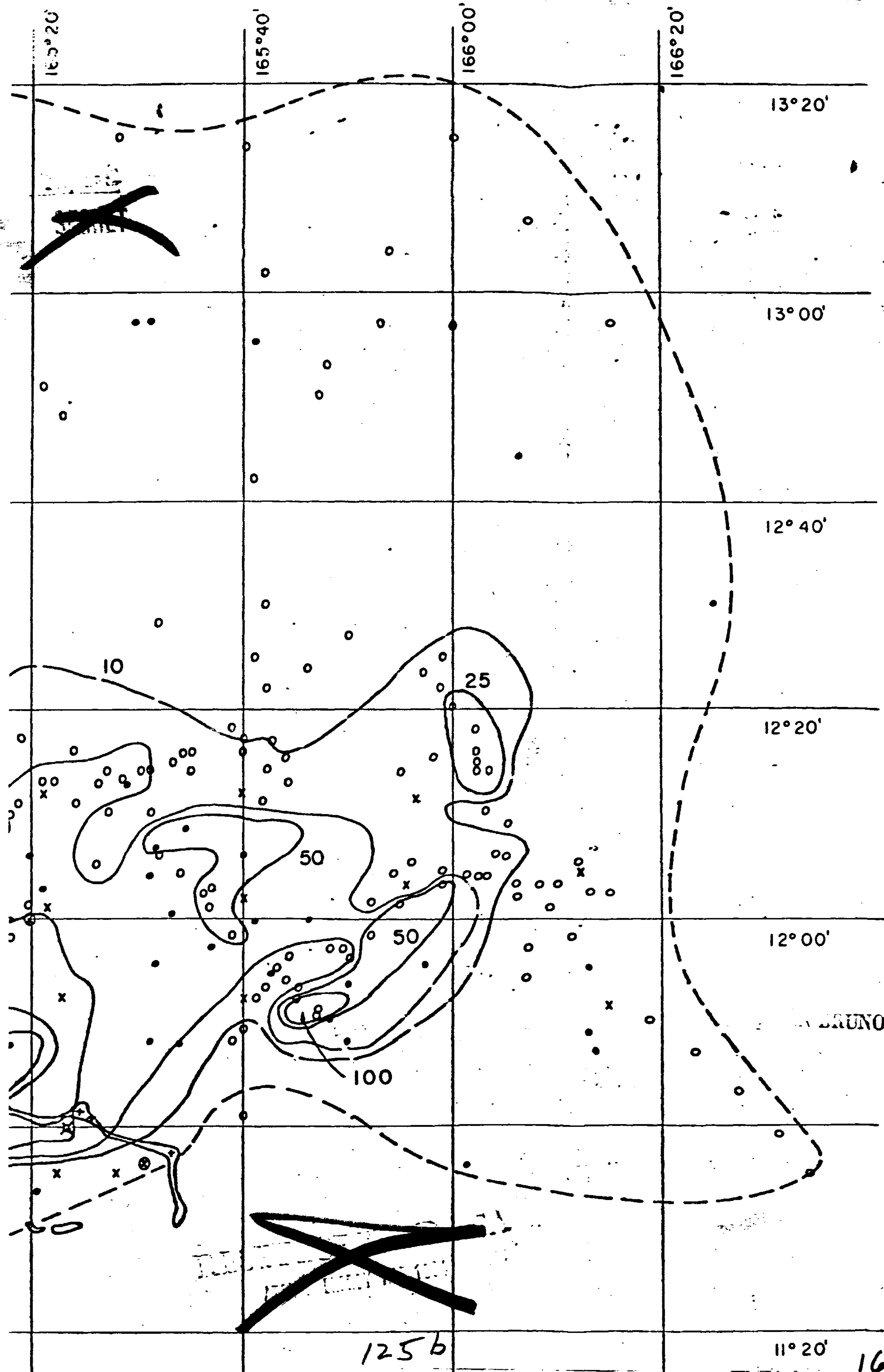
Aerial Survey
Skiff and Raft
Ship Survey
YAG's, LST and Barges
Land Readings
Ground Zero

125a


165°20'
165°40'
166°00'
166°20'
13°20'
13°00'
12°40'
12°20'
12°00'
11°20'
10
25
50
50
100
125b

discussed in Section 3.1.1.5, although the validity of the water survey data is enhanced by the water surface location of the burst, as discussed in Section 3.3.1.4.

The results of a pre-shot survey on Navajo minus two days are indicated in Figure 3.43. The radioactive "slick" which is indicated west of Bikini Atoll is probably due to water from the Zuni and Flathead craters. Since the readings are appreciable, and will not decay rapidly due to the long time since these shots, care must be taken in interpreting data in this region from subsequent fallout surveys.

The experimentally measured effective depth of penetration which was used to reduce the Navajo survey data varied linearly from 20 meters at 10 hours after shot time to 65 meters at 30 hours, and thenceforth remained constant at the value of 65 meters. The decay exponent which was applied to reduce the data to H/1 hour was 1.39 as determined by measurements in the decay tank aboard the M/V HORIZON.

3.3.2.6 Central Time of Arrival Contours. The central time of arrival contours for the Navajo wind situation have been plotted in Figure 3.44. The data points derived from the sources discussed in Section 3.1.1.6 have also been indicated.

3.3.2.7 Ten Hour Exposure Contours. The Navajo ten hour exposure contours, calculated according to the method of Section 3.1.1.7, are presented in Figure 3.45. The corrected data points measured by Project 2.1 are also indicated in the figure.

3.3.2.8 Gross Decay ~~Curves~~ exponent. The observed Np^{239} capture to fission ratio for Navajo was 0.36. The observed gross decay exponents under various conditions of measurement are summarized in Table 3.5.

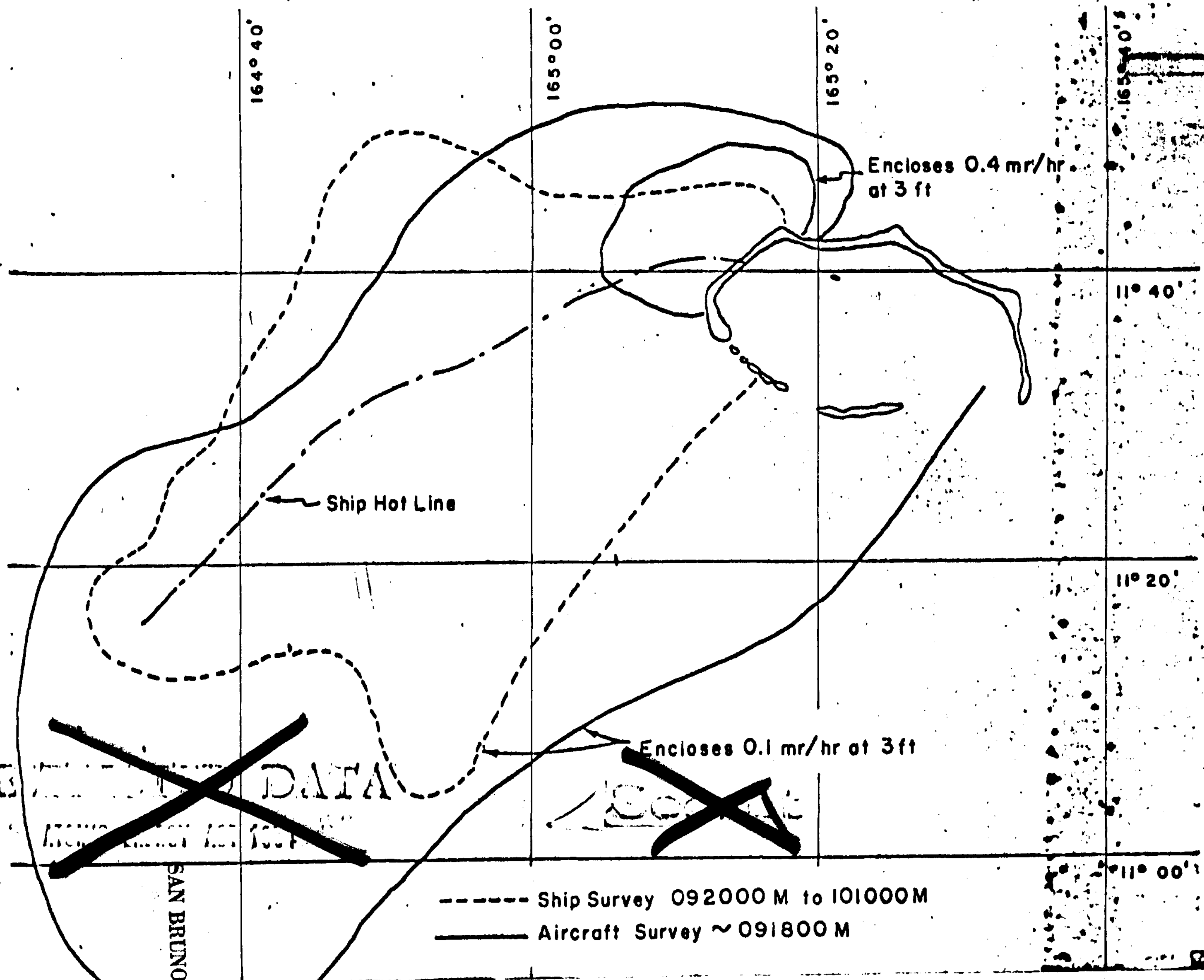


Figure 3.43 Area of Radioactive Effluent From Bikini Atoll on Navajo Minus Two and Minus One Days.

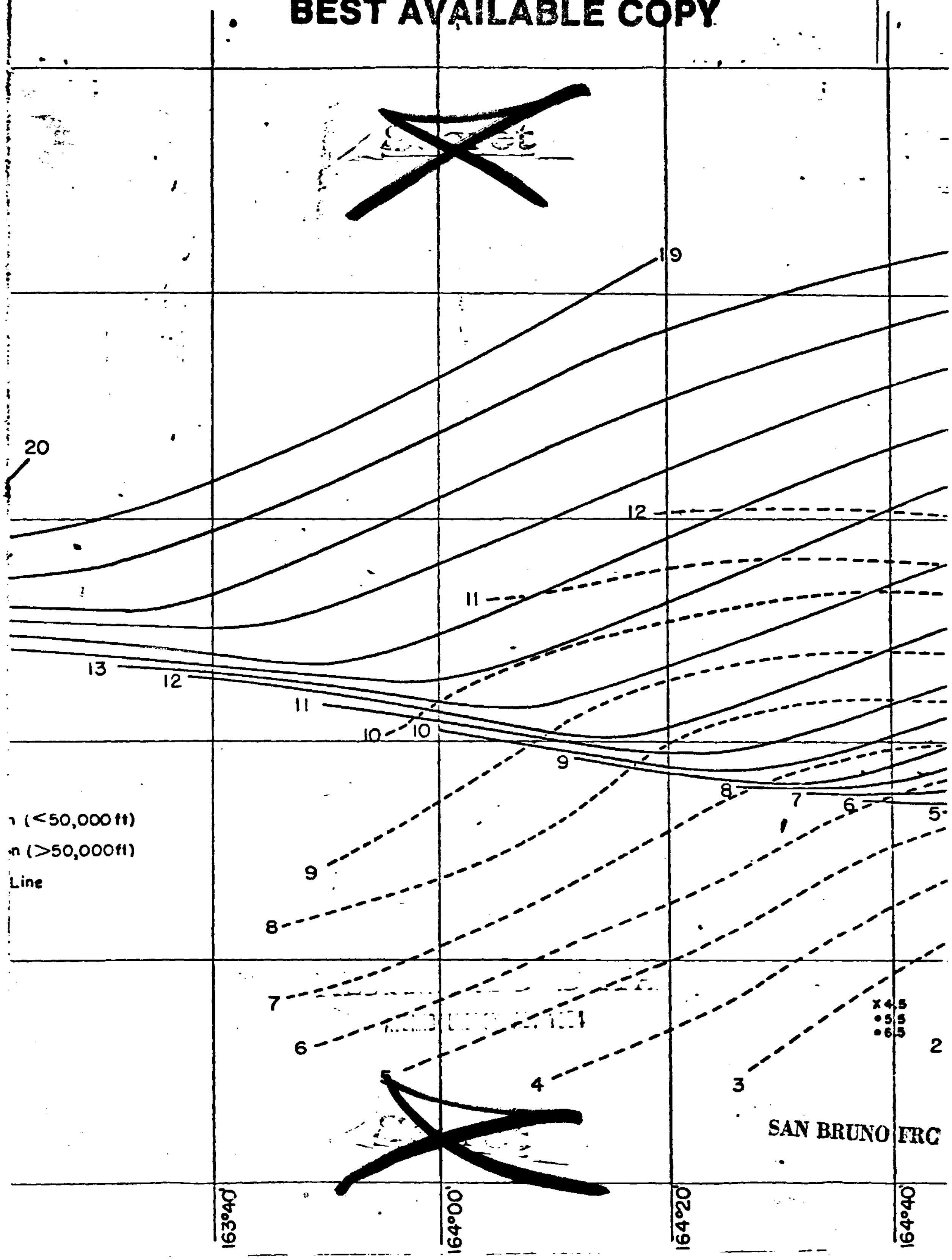
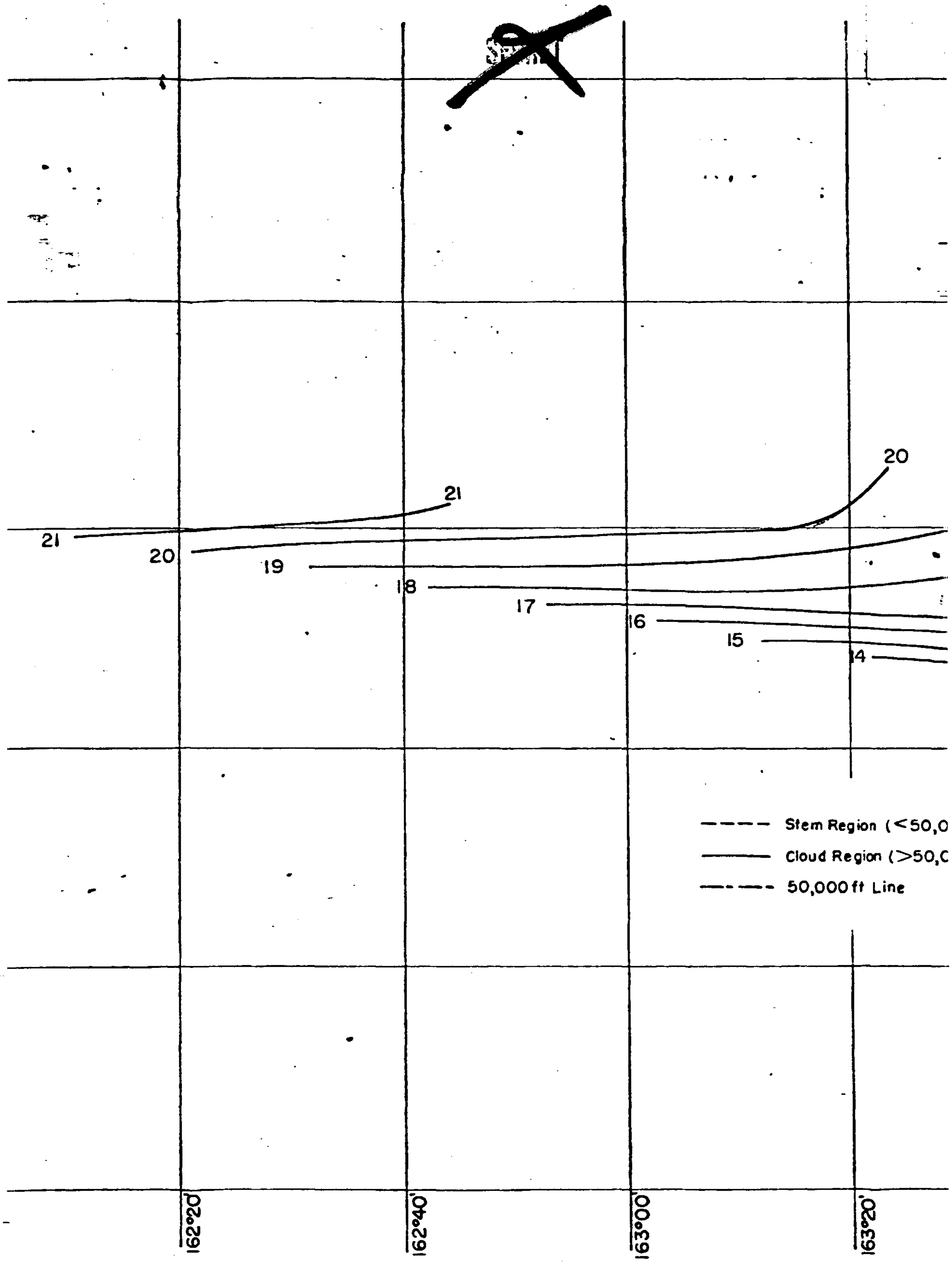


Figure 3.44 Navajo Central Time of Arrival Plot. Times in hours.



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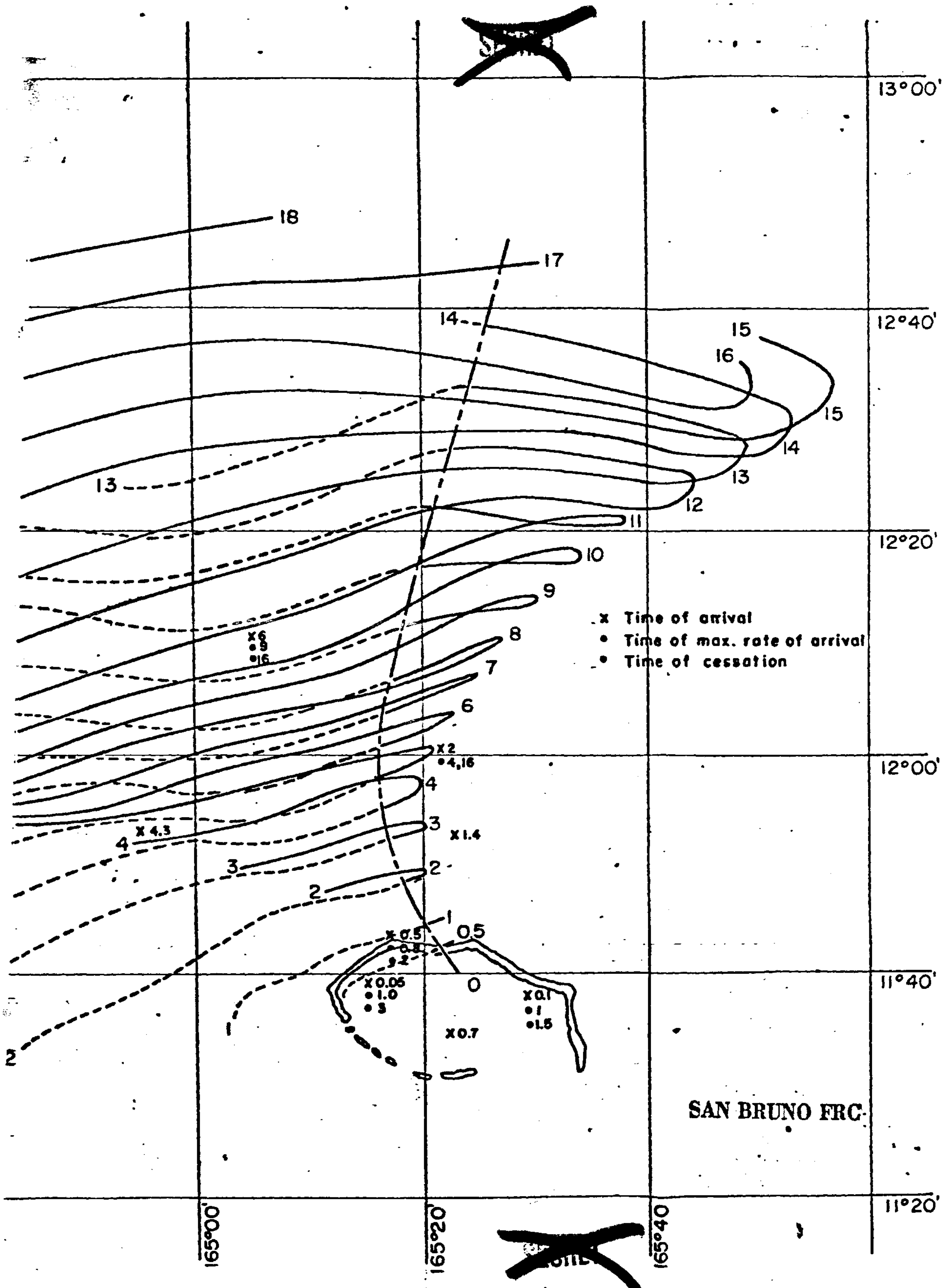
13°00'
12°40'
12°20'
12°00'
11°40'
11°20'
165°00'
165°20'
165°40'
x Time of arrival
• Time of max. rate of arrival
• Time of cessation
X 6
• 9
• 16
X 2
• 4,16
X 4.3
X 1.4
X 0.5
X 0.05
• 1.0
• 3
X 0.1
• 1
• 1.5
X 0.7

RD

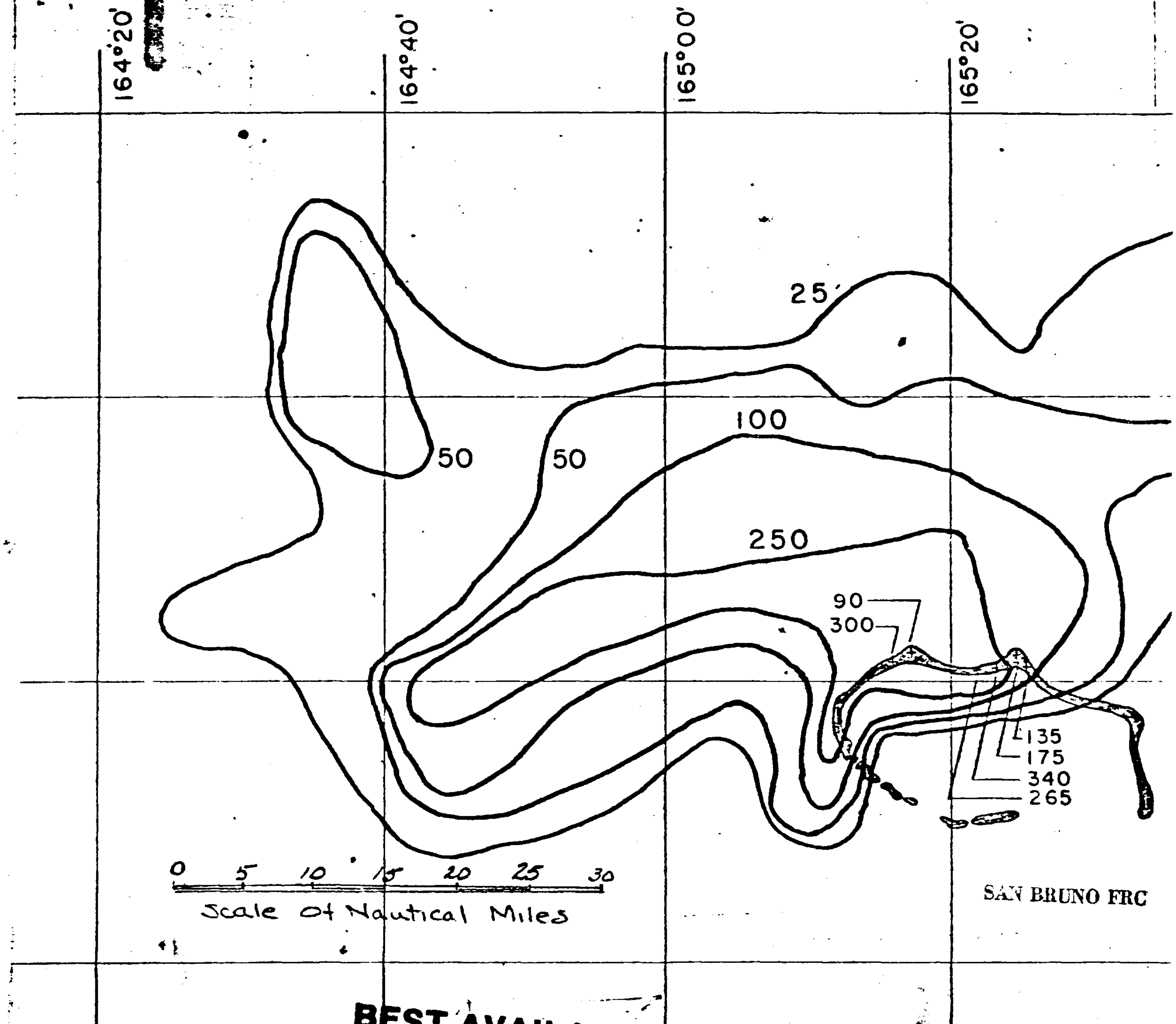

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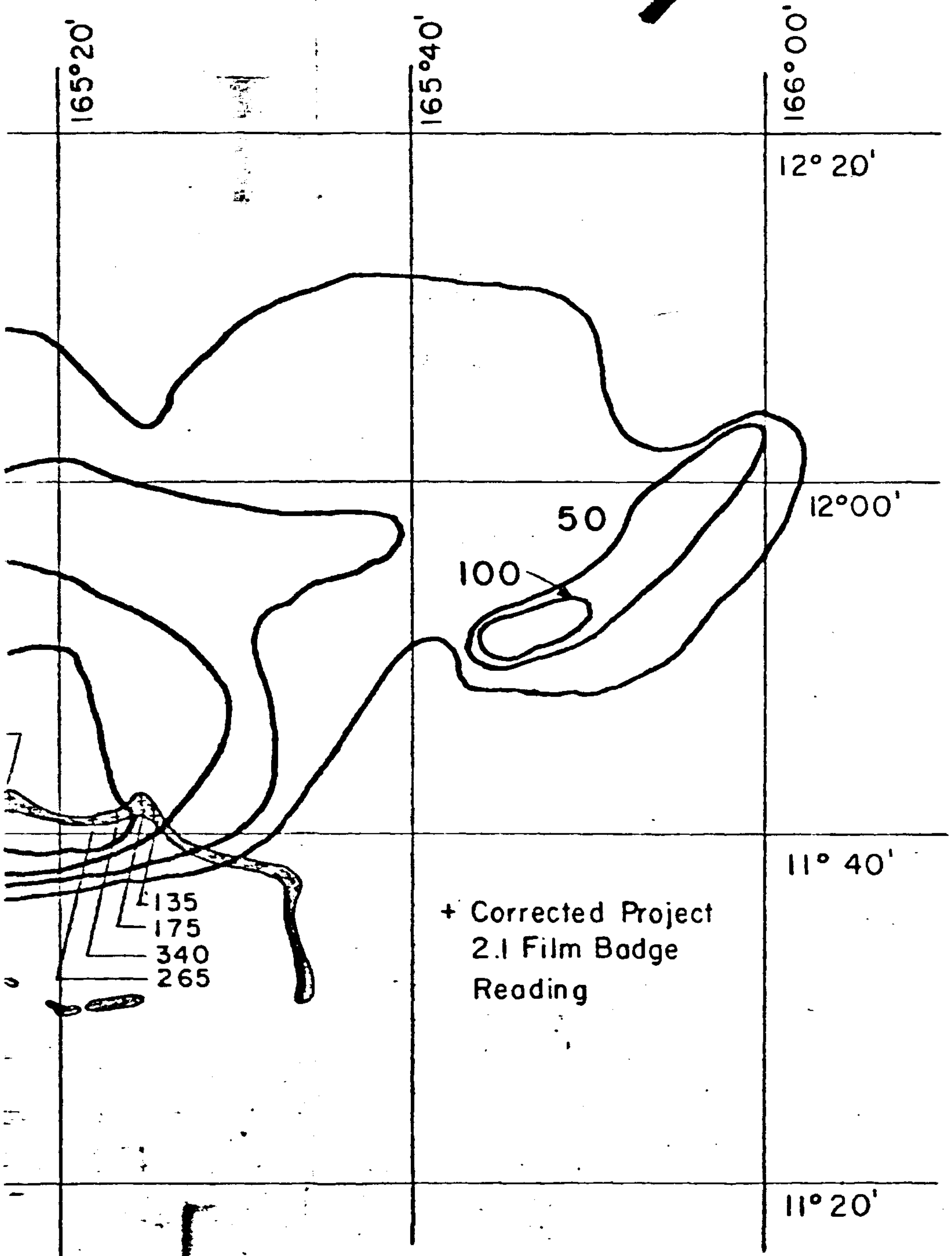
Figure 3.45 Navajo Ten Hour Exposure Contours.



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Exposure Contours.

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TABLE 3.5 GROSS DECAY EXPONENTS FOR NAVAJO

	Time Range (Hours)	5-20	20-50	50-200
Decay Exponent	Gamma Photons*	1.1	0.8	1.1
	Gamma Exposure Rate	-	1.1	1.4
	Beta dis/min	-	1.1	1.2
	Field Gamma Exposure Rate	-	-#	-
	Gamma Exposure in Water	-	1.39	-

* YAG-40 Samples Only

\# Heavy rains on D and D+1 for Navajo apparently removed a large fraction of the contamination from the surface.

CHAPTER 4

DISCUSSION

4.1 TECHNIQUES OF MEASUREMENT

4.1.1 Introduction. During Operation REDWING a number of widely different techniques were used to perform measurements on the fallout field. Some of these techniques were particularly designed to provide accurate analytical measurements. In some cases the techniques employed are adaptable to the problem of a rapid survey of the radiological situation after the burst of a nuclear weapon in a military situation. The purpose of the following discussion is to describe briefly each general technique and to make a necessarily preliminary and incomplete evaluation of its role in the field tests and its possible application to military situations.

4.1.2 Helicopter-Probe Aerial Survey. This technique involves a radiation sensing probe suspended below a helicopter by a long cable. It is particularly useful in acquiring accurate readings at a controlled distance above a land surface. In general, the readings correspond to measurements by a survey instrument which has been hand-carried to the location, except that the dosage to the personnel has been greatly reduced by placing them above and away from the field in the helicopter.

Over smooth terrain the readings probably give an accurate measure of the density of active sources on the ground. However, the effective source is a circle of radius 300 to 500 feet, and any terrain irregularities which would shield part of the source from the instrument would cause the readings to be low. The meter readings would still represent the dosage to personnel located at that position, but would not be a measure of the surface density of radioactive sources (curie/m^2).

The applicability of the technique to military situations is limited to obtaining readings at a few critical locations in a fallout pattern. A small cleared area is required and the present design of probe is not useful over water. The accuracy of the measurement is greater than needed for a complete survey and the time involved for the survey of an extensive fallout area is too long.

4.1.3 Collection of Fallout Samples. The direct collection of fallout samples is an essential part of the analytical program at weapons effects tests. However, the question to be considered now is whether it is good technique for evaluating the surface density of active material.

The laboratory measurements on fallout samples to determine their absolute activity can be made very accurately with fixed geometry counting techniques. The main limitation is in the actual collection of the sample. The requirements for the collector are that it produce negligible disturbance in the air flow pattern and that it retain any material impinging upon it. These requirements must be met over all angles of incidence, corresponding to various particle sizes, and for particle types varying from a fine aerosol to a dry dust. Further experimentation is needed to develop such ideal collectors.

Clearly the collection of material is not a practical matter under operational military situations, since the collectors can not be placed before the event and there is a long time delay involved with recovery of samples and transportation to an uncontaminated laboratory.

4.1.4 Radiation Readings on Ship's Deck Surfaces. The deck surface of the YAG's represented a source field large enough that only a small correction was needed to convert an ~~dose~~ exposure rate reading above the deck to an infinite field reading. However, preliminary data indicate that the fine aerosol type of material does not readily collect on the deck surfaces and large dry material may be blown off. Therefore, such deck readings may tend to be low and must be correlated with other sources of data.

4.1.5 Radiation Versus Depth Profiles in the Ocean. When the nature of the burst is such that most of the fallout activity will be dissolved in the surface layer of ocean water, the radiation versus depth profile is a very useful technique for making an absolute activity measurement. The observations during Operation CASTLE and the present experiments indicate that most of the activity remains above the thermocline (80 - 150 meters depth) for periods of many days and therefore is accessible to direct measurement using simply constructed probes. These readings are calibrated in terms of curies/m^3 by analyzing water samples in a laboratory.

The limitations of this type of measurement for land surface (island) bursts, in which much of the activity is associated with sizeable particulate, are still undetermined. From the measurements performed at Operation REDWING it appears that at least half of the total deposited active material remains in the surface layer, but this fraction may vary greatly with position. For example, the close-in high exposure rate areas may have most of the material, which is associated with the larger particles, disappearing below the thermocline. Since these areas only ~~represent~~ received a small portion of the total ~~weapon~~ fallout, this would not affect the conclusion above.

One feature of the measurements that needs continuous careful check is the problem of probe contamination. Since the radiation levels in the water are invariably quite low, it is important to make sure that a small amount of activity deposited on the probe is not affecting the answer.

4.1.6 Radiation Readings in the Surface Ocean Layer. A relatively rapid survey of ocean fallout areas can be made using a probe towed behind a ship which measures the radiation field just below the water surface. Interpretation of these readings in terms of total fallout material involves the assumption of an average depth of mixing, guided by the results of the radiation versus depth profiles. This technique must therefore be applied with care, particularly in regions of recent fallout and regions where fallout was in the form of large particulate.

4.1.7 Radiation Readings in Air Over the Ocean. Radiation readings taken in an airplane flying above contaminated ocean water, when corrected for the absorption of the air, measure the concentration of activity in the surface layer of water and, therefore, are subject to the limitations discussed in Section 4.1.6. In addition, the readings at practical flight altitudes ($>$300 feet), represents averaging over an area whose radius is of the order of 1,000 feet, and therefore this method must be used with care in areas of high gradients in the radiation field. However, the survey can be performed faster than that performed by a surface vessel and therefore can outline the fallout pattern in a short time.

In performing these aerial surveys it is important that the aircraft arrive over the fallout area after the radioactive material has ceased to come down. A relatively small amount of contamination alighting on the aircraft can easily mask the radiation from the water surface, because the water greatly dilutes the radioactive sources.

4.1.8 Radiation Readings in Air Over Land. During Operation REDWING the technique of taking radiation readings in an airplane flying over land was not used extensively because of the small amount of land area present. This method has been used for tests at the Nevada Test Site.

The principal limitation ofthis technique is in the region of high fields, and associated large gradients. Since the readings do represent averages over sizeable areas the features of the pattern will be smeared out over distances of the order of 1,000 feet. Furthermore, over irregular terrain the airplane may be forced to fly higher than 300 feet and hence average over a slightly larger area.

Contamination of the aircraft must again be avoided, although the problem is not as critical as it is on a survey over water. On the other hand, the higher readings from the land increase the problem of dosage to the aircraft crew. BEST AVAILABLE COPY

The aerial survey system is applicable to practical military situations since it does roughly outline the areas denied to personnel operations in a fairly short time. However, care must still be taken because local hot spots in the field may be smoothed out by the survey, which could nevertheless inflict serious dosages on personnel.

Readings taken by helicopters hovering at low altitudes above land surfaces have been used principally in the RadSafe surveys during Operation REDWING. Apart from the slight decrease in dosage to personnel compared with ground operations, this method has additional merit when used over rough terrain. If it is desired to evaluate the density of active sources, rather than the dosage to personnel at a particular location, a meter held at a moderate altitude is less likely to be shielded from part of the source field than one held at 3 feet over the ground. Before such methods are used for accurate work, however, it will be necessary to perform careful altitude absorption calibration experiments.

4.1.9 Droppable Radiation Detector-Telemeter Units. A technique which has been tested unsuccessfully at Operation TEAPOT and Operation REDWING, but which has promise if further developed is one involving the use of a radiation detector and telemeter unit which can be dropped onto a contaminated area. The radiation readings are then received at the drop aircraft which can retire far enough away to be out of the intensive radiation.

This technique is particularly applicable to measuring the intense fields near the crater from a nuclear burst. It is limited to a number of data points equal to the number of detector-telemeter units available. The fact that the equipment can continue to send information over a long period of time makes it particularly useful for field tests since it supplies decay as well as instantaneous exposure rate data.

At REDWING, this technique was known as the "Beach Ball Project" and was undertaken as an effort incidental to that of a major project and lack of results should not be used as the basis for prejudice against this technique.

4.2 LIMITATIONS OF PRELIMINARY DATA

4.2.1 Introduction. This presentation of preliminary data and the ensuing discussion were completed only a few weeks after the last event in Operation REDWING. Therefore, it is to be reemphasized that the data are subject to large changes and their interpretation may also be altered when the final reduction of the data is complete. However, the results of the fallout program are of military importance immediately, and it is to be hoped that the errors introduced by presenting preliminary and possibly incorrect data will be more than compensated by the advantages of having a preliminary picture available at an early time. It is the purpose of the following discussion to evaluate the sources of additional data and the most probable recalibrations which will be provided by the data in the Program 2 projects' final reports. The fact that the data is preliminary and some changes can be anticipated with time should not be construed to mean that a fairly good picture of the fallout problem in operational situations is not available at this time.

4.2.2 Radiation Measurements in the Nuclear ~~Cloud~~ mushroom. As discussed in Section 3.1.1.2, the preliminary data on exposure rate versus position in the nuclear ~~cloud~~ mushroom is subject to large changes - primarily from the following sources: (1) The identification of a radiation record with a particular rocket may be changed. If this becomes necessary, a major change in the positions of the readings will result. (2) A redetermination of the zero time on the traces is likely to shift the radiation readings along the trajectory. (3) Recalibration of similar detectors, particularly in high radiation fields, will probably indicate a nonlinearity in the response curve, which may change the values of the higher readings. (4) The trajectory data will probably be changed slightly.

4.2.3 Land Surface Readings. The land surface readings are probably subject to the least change compared to the remainder of the data. The principal changes will come about in the use of experimental decay curves, or at least theoretical decay curves based on the measured capture to fission ratio, rather than the simplified $t^{-1.0}$ and $t^{-1.2}$ relationships.

4.2.4 Water Survey Readings. The water survey readings will be subject to major recalibrations based on an analysis of the observed depths of penetration as a function of time after arrival and position in the fallout pattern and on absolute counting of the water samples. The average depths of penetration used in this report represent at best a method of presenting the data in a relative fashion indicating the rough magnitude of the contamination. When such a recalibration is performed the calculation of the total material observed, and hence the fraction of the weapon locally deposited, can be performed in a significant fashion. At present such a calculation serves only to demonstrate that the readings are of the correct order of magnitude, and even a comparison of the weapon fractions between different events is doubtful.

Preliminary measurements on Tewa fallout made at NRDL has demonstrated a large variation of solubility rate and gamma spectra with time of contact with water (reference 30). Complete analysis of various factors, including variation of particle size with distance from ground zero and dependence of settling rate on particle size and solubility, is required to establish a fully reliable set of contours.

4.2.5 Aerial Survey Readings. The aerial survey readings are subject to the same recalibrations discussed in Section 4.2.4 and in addition must be recorrected for the air absorption. Absorption experiments performed at Operation REDWING and some theoretical calculations should provide the basis for this recalibration.

4.2.6 Sample Readings. The relative radiation levels derived from sample readings are probably subject to the largest changes. Aside from the problem of collection efficiency, the values used in this preliminary report represent crude monitor readings of the samples measured in standard geometry situations, but under conditions of appreciable background radiation. Only the careful analysis and counting, done later in the continental laboratories, can correctly determine the relative fields and can, in addition, furnish the absolute surface density of active materials.

4.3 DISTRIBUTION OF ACTIVITY IN THE STABILIZED CLOUD

4.3.1 Introduction. There is no strong reason to expect the distribution of activity in the stabilized cloud to be a function of the geological environment of the burst point, and no experimental evidence to indicate any such phenomenon. Therefore, the observations on all the documented shots will be discussed together, keeping in mind that for comparison purposes the readings should be divided by the fractional radiological yield to be reduced to the common basis of a 100 percent fission weapon.

4.3.2 Rocket Measuremnts. The rocket exposure rate measurements indicate that the active material is not distributed uniformly through the cloud. As a matter of fact, if the material were distributed proportionally to the air density, the readings should be constant in the cloud and this is not the case. The individual exposure rate traces generally indicate a rapid peaking and subsequent decline while the rocket is still within the visible cloud. Therefore, as demonstrated particularly in Figures 3.2, ~~3.2a~~ 3.4, ~~3.22a~~ 3.25, and ~~3.34a~~ 3.35, most of the activity is probably in a thin layer, which is ~~probably~~ located just above the base of the visible ~~mushroom top~~ cloud.

[redacted]

The radial variation is also interesting. There is some evidence for a slight decrease in concentration at the center (above the stem), a peaking at a distance of about one-third of the visible cloud radius, and a subsequent decrease to the outer regions where the concentration appears to be about one quarter of its peak value. Crudely speaking, the active material appears to be concentrated as a "washer" with some material of lesser activity spread into the rest of the visible cloud.

The limited observations in the stem indicate peak activity concentrations less than those directly above in the cloud by a factor of ten or more. The radiological stem has dimensions no larger than the visible stem. Therefore, in view of the relative volumes, an inappreciable amount of material exists in the stem at the altitudes observed.

4.3.3 Manned Aircraft Measurements. The actual exposure rates measured by the aircraft penetrations were in general lower than those calculated from the rocket data at the same altitudes. The reason for this discrepancy is not yet clear. Of course, no aircraft penetrations were performed as early as the rocket flights on these events, but previous experience with the penetrations does indicate the $t^{-2.0}$ decay extrapolation of the aircraft data to be an overestimate, if anything.

The observations of the aircraft in the stem support the conclusion that the concentration of activity is small compared to that in the ~~mushroom-top~~ cloud. These flights, as well as the rocket data, only draw this conclusion for the upper parts of the stem at the times involved. They shed no light on the question of heavy particulate which might have fallen before the observations were made, or for the part of the stem below 25,000 feet.

4.3.4 Fallout Pattern Indications. At present no complete analysis of the fallout radiation pattern in terms of the particle fall plot and the finite cloud dimension have been performed. However, some preliminary conclusions can be drawn from the data. It should be noted that the H+1 hour exposure rate at a particular point should be determined roughly by the activity in the initial cloud associated with the height and particle size intervals which encompass the point on the particle fall plot, divided by the area between the corresponding height and particle size lines on the plot. Therefore, whenever the height lines come close together there should be an enhancement of the radiation field due to the wind structure and not because of any properties of the initial cloud. A limit to the above statement is implied by the finite horizontal dimensionsof the cloud, which spread the activity over a minimum area even if there is no shear in the wind structure.

The following features of the fallout radiation pattern appear from a cursory inspection combined with the particle fall plot:

a. The outer boundary of significant fallout seems to be at approximately the 60 micron line. However, the area up to the 75 micron line is subject to such low activity concentrations arriving at late times that it is not of concern in military operations.

b. The effective cloud diameter for the larger particles must be smaller than the visual cloud diameter to explain the rapid decrease of contamination on islands in the upwind and crosswind directions. A careful activity versus particle size analysis for the land station samples will be needed to establish this effect quantitatively.

c. Large particles from the lower stem region may produce very intense radiation areas a few miles downwind from the shot point. The Zuni Shot gave no indications of this effect, but all the barge shots produced heavy contamination on Sites Able and Charlie. This contamination could not be crosswind deposition from the cloud, because Site How, which was almost an equal distance in an opposite direction for Navajo and Flathead, as well as the YFNB barge which was closer, did not show these high readings.

d. The most significant fallout comes from the base of the nuclear cloud. The "hot line" in the pattern invariably fell in the direction corresponding to 50-60 thousand foot lines. The concentration of altitude lines due to the wind reversal at these altitudes is not enough to explain the magnitude of the effect. Furthermore, the regions that received fallout from higher parts of the cloud were contaminated to a small extent. For example, on event Tewa a part of the 75-80 thousand foot fallout actually fell on Eniwetok Atoll, but did not produce enough contamination to warrant evacuation.

4.4 CHARACTERIZATION OF FALLOUT MATERIAL

4.4.1 Introduction. Only fragmentary information on activity versus particle size distributions was available at the early date of this report. Most of the data on the particle sizes at various positions in the initial cloud will come from analysis of the intermittent fallout collector samples in which the particle size and time of arrival can be correlated to a unique position in the cloud. Since this information must come from more detailed analysis, only preliminary data as gathered from the correlation between the fallout radiation plot and the particle fall plot can be discussed here.

The chemical and radiophysical analyses of the fallout material are also matters for continental laboratory work. However, the resulting data will deal mainly with fractionation and hence with theories of formation of the active material. At present, it is not possible to include these theories into fallout model calculations in any significant fashion. Fractionation may affect the radiation dosage through its modification of the gamma energy spectrum and the decay curve, but such effects are not well enough known to be incorporated now.

The physical appearance and chemical nature of the fallout has been roughly evaluated at the land stations and in the YAG 40 laboratory. Further data on other samples are being produced in the home laboratories. For example, as stated in paragraph 4.2.4, some information has already been developed on the characteristics of particle solubility in a Zone of Interior laboratory.

4.4.2 Land Surface Burst. The data on the particulate matter for land surface bursts presented in this report is applicable only to land consisting of coral with nearby salt water. Therefore, some of the conclusions may have to be modified when discussing bursts over other, more usual, types of ground.

A cursory inspection of the particle fall plots and fallout radiation plots for Zuni and Tewa indicates that the most intense regions are associated with particles in the 100-200 micron size range. The LaCrosse plots indicate that the activity on the surface appears to increase when going from 350 toward 200 micron particles, although the documentation did not extend to the sizes below 250 microns. Since the intense pattern to the west of Tewa appears to be short, any important lower stem activity is probably associated with very large particles.

In general, the fallout material from the land surface bursts was quite dry, even though there was an appreciable amount of water in the environment of the shot point. The chemical nature of the material was in general modification of coral, namely $CaCO_3$, $Ca(OH)_2$, and some CaO. Usually other materials present near the shot point also appeared in the fallout, e.g., the iron in the LaCrosse event.

4.4.3 Air Burst. The Cherokee Shot at Operation REDWING represented an air burst over water. The extensive survey of the downwind areas subsequent to this detonation established that the fallout radiation levels were not of military importance for this type of burst. Clearly the fission product material must have become associated with particulate so small that the local fallout was negligible. In this case the problem has become one of the world-wide contamination type and therefore is beyond the scope of this report. BEST AVAILABLE COPY

The requirement still remains to evaluate the contamination from a megaton yield weapon detonated under minimal air burst conditions over land. To date it has been established that air bursts of kiloton yield weapons above land and megaton yield weapons over water do not produce significant local contamination. However, the probability that an air burst of a megaton yield weapon over land produces contamination is ~~as large~~ the same after the Cherokee test as it was before. The reason is that the mechanisms discussed in Section 1.2.3 by which such a burst could produce local contamination do not apply to a burst above water. If surface material (sea water) from Cherokee had caught up with the fireball in time to have the fission products deposited on it, the water would have undoubtedly evaporated. Recondensation of the water, if it occured at all, would probably be in the form of very small droplets which would not be locally deposited.

Therefore, it may be unlikely that bursts of a megaton yield weapon over land produce significant local contamination, but it is possible and the Cherokee test does not negate such a possibility.

4.4.4 Water Surface Burst. The effective particle size for water surface bursts appears to be much the same as for land surface bursts. Again the intense regions of the fallout pattern seem to be associated with 100-200 micron material. Furthermore, the stem region to the west seems to have the same character as for land surface bursts.

One extra phenomenon which can easily occur in this type of shot is a time change of the effective size of a particle (droplet). As water evaporates or condenses on the drop it could fall according to various different sizes as it comes down. In addition, ice particles which result from frozen drops will have different fall characteristics than the drops. Sublimation of ice particles will also introduce variations. Phenomena of this nature could introduce major modifications into the particle fall plot, which present knowledge has no way to predict.

The ~~nature of the~~ material from water surface shots seems to be predominantly salt. The very high concentration of salt may imply a large degree of evaporation has taken place during the particle's travel earthward. The actual activity seems to be associated with a very small nucleus amidst this slurry type salty droplet.

In general it appears that the prediction of fallout from water surface bursts can be made using similar parameters to those for land surface bursts.

4.5 RELATIVE AREAS OF CONTAMINATION

4.5.1 Introduction. The characteristic dimensions of a fallout pattern, e.g., downwind distance, crosswind distance, etc. will depend quite markedly on the existing wind profile. For example, a wind profile having very little directional shear and strong velocities would be expected to produce a long, cigar shaped pattern whereas the high shear situation which is common in the Pacific Proving Ground produces a wider and shorter pattern. If there is any hope of characterizing the fallout region by any parameters characteristic of ~~the~~ a weapon and its environment and relatively independent of the wind conditions, ~~the~~ such parameters ~~should be chosen to~~ might be the areas enclosed by the various radiation contours. In particular, the integral of the H+1 hour exposure rates over ~~the~~ a given contour area ~~must~~ might be characteristic of the detonation only, ~~since~~ it represents the portion of the radiological yield which has been deposited ~~[illegible]~~ within the contour.

4.5.2 Background. The only surface events previous to Operation REDWING on which sufficient fallout information was available to infer areas of contours were the JANGLE surface shot and some of the Operation CASTLE events. Of the latter ones, the CASTLE Bravo surface shot contours have only been predicted from an analysis of the winds with some normalization from sparse data points. The water survey data from Shots Yankee and Nectar, Operation CASTLE, yielded contour area data for water surface (barge) shots. For reference, these data have been summarized in Table 4.1

TABLE 4.1 SUMMARY OF PREVIOUS SHOTS' EXPOSURE RATE CONTOUR AREAS

DELETED

NOTE: *Reference 10.
#Reference 11.

The above contour areas, except the JANGLE surface data, were multiplied by a factor of 4/3 and presented on the plot of Figure 4.1 of area versus one hour exposure rate. The factor was desired to normalize all data to a hypothetical 100 percent radiological yield weapon. The predicted contour areas for 50 KT, 500 KT, and 5 MT bursts from Reference 29 have also been indicated on Figure 4.1.

An estimate of the radiological yield accounted for by the fallout data can be derived by a rough numerical integration of the exposure rate over the area. (See Appendix D).

4.5.3 REDWING Results. The data on the areas of the contours drawn from the preliminary data of this report have been presented in Table 4.2. These data from the two land surface shots, Zuni and Tewa, and the two water surface shots, Flathead and Navajo, have also been presented in Figure 4.2. For the figure, the radiation levels were in all cases [redacted] weapon. THESE CONTOURS ARE EXTRAPOLATED FROM PRELIMINARY DATA AND MUST BE USED WITH CAUTION. See Appendix E for estimates of the fraction of activity in the local fall out.

4.5.4 Ten Hour Exposure Areas. The ten hour exposure areas are not of direct significance to fallout models, but are of primary concern in the military effects of fallout. The relative areas of the various contours have been listed in Table 4.3 for the four REDWING shots on which the Program 2 projects gathered complete fallout data. The data have also been plotted in Figure 4.3, where the exposure values have been normalized to a 100% radiological yield weapon.

4.5.5 Comparison. In general the differences of the contour areas between the [redacted] are not significant in view of the approximations used in the preliminary data reduction.

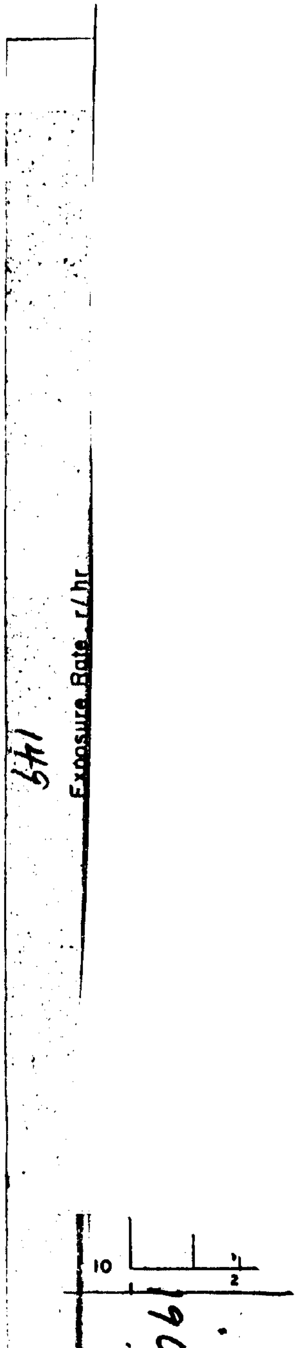

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Figure 4.1 Areas of Exposure Rate Contours on Previous Shots. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.

Area, sq mi

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Figure 4.2 Areas of Exposure Rate Contours on REDWING Shots. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.

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TABLE 4.2 SUMMARY OF EXPOSURE RATE CONTOUR AREAS, OPERATION REDWING*

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NOTE: # Very doubtful - represents rough estimate of boundary of fallout pattern.

* CONTOUR AREAS EXTRAPOLATED FROM PRELIMINARY DATA AND MUST BE USED WITH CAUTION.

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TABLE 4.3 SUMMARY OF TEN HOUR EXPOSURE CONTOUR AREAS, OPERATION REDWING*

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NOTE: *CONTOUR AREAS EXTRAPOLATED FROM PRELIMINARY DATA AND MUST BE USED WITH CAUTION.

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In particular the curve for Navajo is probably too high, because the [redacted] and the resultant low activities in the outer regions of the fallout area, caused the background radiation levels from previous shots to have an appreciable effect. Since in the present data reduction the pre-shot background radiation was not subtracted, the contour areas as presented are probably too large.

Comparison between the values predicted on Page 97 "Capabilities of Atomic Weapons," Reference 29 and those measured in these experiments is more uncertain than a comparison between events, because any errors in the ~~absolute~~ conversion factors ~~may contribute appreciably~~ used in reducing fallout data are uniformly applied. In general, the measured contour areas are larger than the predicted values. However, an error in the conversion from radiation measurements in the water to the calculated value over an equivalent land surface could have this effect. Laboratory work being performed at present, as well as more complete data reduction, should resolve the questions about conversion factors.

No comparison between experiment and prediction of crosswind distance, downwind distance, and ground zero circle diameter can be made at this time. Some of these distances are quite sensitive to the actual wind conditions. Since the wind profile which usually existed on shot days at the Pacific Proving Grounds is not typical of the continental winds, there would be no significance to such a comparison.

4.6 EXAMPLES OF FALLOUT PATTERNS IN THE CONTINENTAL UNITED STATES

4.6.1 Introduction. To perform an accurate prediction of the fallout pattern from a burst at a particular location, a complete analysis of the REDWING data in terms of a fallout prediction model should be performed, which would then be applied to the calculation of the fallout from the assumed wind profile. However, the accuracy of the preliminary data does not justify such a detailed analysis in the limited time available for the preparation of this report. Therefore the patterns have been constructed from the following assumptions:

a. The assumed weapon was a 5 MT total yield, [redacted] land surface burst.

b. The ten hour exposure contours had the same areas as those observed for Tewa.

c. The location of the ten hour exposure contours was chosen to represent an estimate of the relative positions in the fallout pattern. The contours around ground zero were slightly distorted and reproduced with the same area. The outer boundary of the pattern was determined by the particle fall plot expanded by a cloud diameter of 30 miles in the small particle size areas, and by about 5 miles around ground zero. The center of the downwind maximum, which clearly occurred for both Zuni and Tewa, was chosen at the 50,000 feet, 100 micron point in the particle fall plot. The effect of the strong non-shear wind pattern on the continent is to displace this maximum about 150-200 miles downwind, although during the tests it was approximately 50-100 miles from ground zero. A detailed model calculation will be needed to verify this position. Actually the entire area between ground zero and this maximum will probably receive a lethal dose for personnel exposed for 10 hours to the fallout.

4.6.2 Comparison of Wind Profiles. The wind profile which was incorporated into the particle fall, time of arrival, and fallout plots given in Chapter 3 was generally as follows: Easterly winds (Trades) up to 20-25,000 feet with speeds of 10 to 20 knots, South westerly winds (Westerlies) to 50-55,000 feet with speeds of 20-30 knots, and then turning through the south to the upper Easterlies with speeds increasing from 15 to 80 knots with altitude. The two major shear areas (20-25,000 feet and 50-55,000 feet) appear to be typical of mid-Pacific torrid latitudes. On the other hand, the United States and most of Europe lie in temperate latitudes which are characterized by winds generally from the west which have little directional shear. Consequently there will be a different shape to the fallout pattern under these conditions. For illustration, representative winter winds have been selected to distribute the fallout from hypothetical [redacted] surface bursts at Washington, D. C. and Santa Monica, California.

4.6.3 Washington, D. C. and the East Coast. Figure 4.4 is taken with ground zero at the Pentagon Building. The fallout pattern[1] encompasses a good portion of the District of Columbia, Arlington County, Virginia and a few small cities such as Alexandria, Va., Annapolis, Md., Dover, Del., and Atlantic City, N.J., covering an area of 7,000 square miles (of land and Delaware and Chesapeake Bays) and a population of 1,900,000. Of these people 900,000 will receive fallout which will be lethal to almost all exposed personnel (ten hour exposure of 500 r). In close, (6-10 mile radius) of course, there is a compounding of blast, thermal, and radiological effects which will produce casualties, and only the area outside of this region should be considered in evaluating casualties from fallout alone.

1./ CONTOUR DIMENSIONS EXTRAPOLATED FROM PRELIMINARY DATA AND MUST BE USED WITH EXTREME CAUTION.

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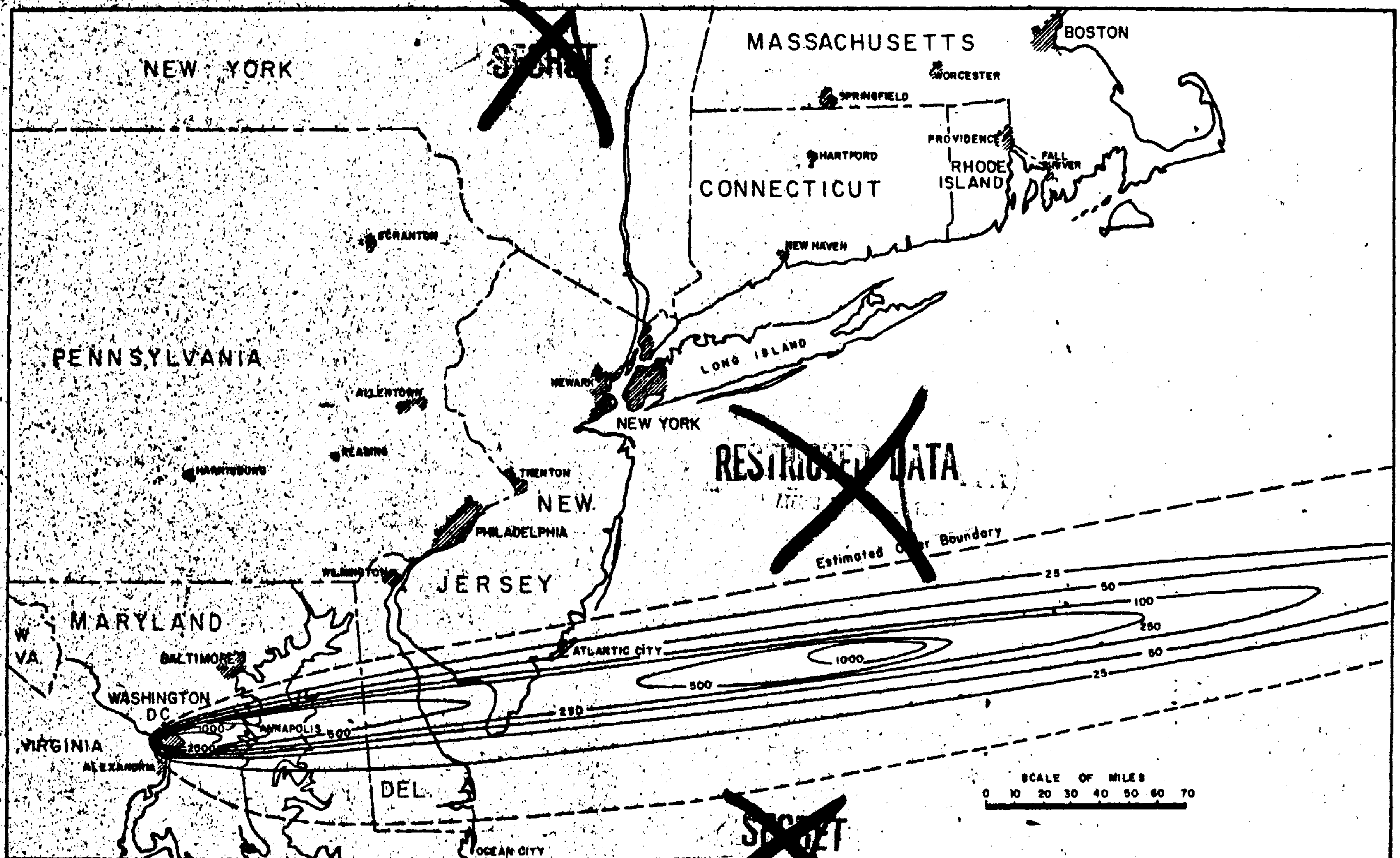

Figure A.4 Washington, D. C. Ten Hour Exposure Contours Estimated From REDWING Experience. A [redacted] yield surface burst is assumed with a representative winter wind structure. Contour values given in r. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.

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An examination of Figure 4.4 will show that over 50% of the potential casualty producing region falls in the North Atlantic Ocean. Therefore it is certainly possible to construct examples in which the entire fallout region will encompass populated areas.

It is interesting to speculate on the pattern produced by less representative winds, for example with the pattern moved 30° counterclockwise so that the 250 r ten hour exposure contour extends well past Philadelphia, Pa., New York City, and through Connecticut.

This pattern has the following areas:1/

a. A lethal area 200 miles long, 10 miles wide which has a total area of 1700 square miles.

b. A sickness area 350 miles long, 15 miles wide which has a total area of 3800 square miles.

c. An area of biological concern 500 miles long, 30 miles wide, which has a total area of 12,000 square miles.

If the weapon chosen for illustration was of the same total yield but had a small fission yield [redacted] then the pattern would have:

a. A lethal area 25 miles long, 5 miles wide which has a total area of 90 square miles. This area only protrudes slightly beyond the area of major bomb damage.

b. A sickness area 42 miles long (probably in two parts), 14 miles wide, which has a total area of 450 square miles.

1/ Ten hour exposure values are chosen as follows: Lethal - 500 r, sickness - 250 r, biological concern - 50 r. These terms refer to the effect on exposed personnel and do not take shielding into account.

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c. An area of biological concern 350 miles long, 15 miles wide, which has a total area of 3,800 square miles.

4.6.4 Southern California Area. Figure 4.5 has been drawn with the ground zero at Santa Monica, California. The pattern takes in nearly all of the Metropolitan Los Angeles area and a number of smaller cities to the East South East. A lethal dosage to exposed personnel would have been delivered to an area inhabited by approximately $4\frac{1}{2}$ million people. In this example, the downwind maximum area fortunately coincides with a desert area North of the Salton Sea and will contribute very little to the casualties. The areas involved are comparable to those discussed in Section 4.6.3. Again the winds have essentially no directional shear and therefore the pattern appears as a very long, narrow area of contamination.

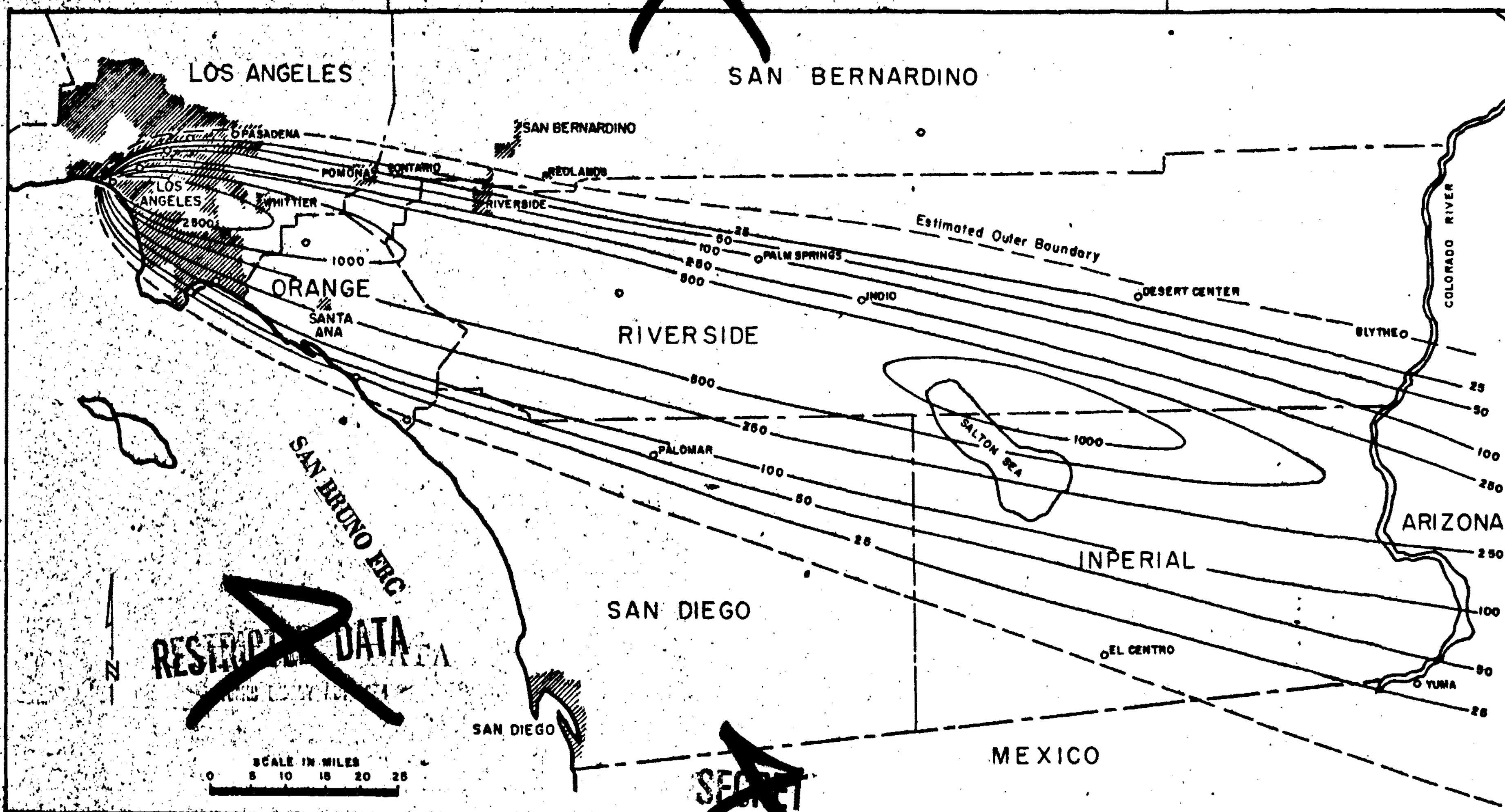

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Figure 4.5 Southern California Ten Hour Exposure Contours Estimated From REDWING Experience. [redacted] surface burst is assumed with a representative winter wind structure. Contour values given in r. EXTRAPOLATED PRELIMINARY DATA. USE WITH CAUTION.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following general conclusions are considered applicable to the experiments reported in this preliminary report:

1. The fallout program successfully accomplished its mission of documenting the activity levels in the nuclear mushroom and the fallout pattern and collecting fallout materials.

2. The data gathered in the field and subsequent laboratory analyses will supply the material for extensive calculations of fallout prediction models.

3. The concentration of activity in the stabilized nuclear cloud appears to be more dense in a layer near the bottom of the cloud than it is in the upper areas. The most intense contours from a 5 MT surface burst apparently originate from approximately 100 micron diameter particles at 50,000 feet elevation, the region of the base of the cloud.

4. The concentration of activity near 30,000 feet in the stem of the mushroom from a 5 MT burst is less than 3 percent of the concentration in the cloud.

5. The techniques used for land, aerial, and oceanographic survey were successful. Some of these techniques can be applied to military situations.

6. Laboratory analysis of water samples and careful analysis of penetration of activity in the ocean will probably provide the basis for an accurate fission and activation product material balance. An estimate of the amount of active material remaining in the upper atmosphere can be made subsequently.

7. Within the accuracy of this preliminary data, the fallout exposure rate produced by a weapon of a given yield is proportional to the fractional radiological yield.

8. The effectiveness of the various fallout survey techniques was greatly enhanced by the coordination provided by the Porgram 2 Control Center.

9. The preliminary data indicates that a [redacted] surface burst would deliver lethal dosages to exposed personnel over an area in excess of 1500 square miles.

10. Exposure rates in excess of 10,000 r/hr at H/1 hour were present in the vicinity of the crater of the Mohawk event.

11. A minimal air burst over water produces no fallout of military significance.

5.2 RECOMMENDATIONS

The only recommendation made on the basis of this preliminary data is to USE CONTOUR INFORMATION WITH CAUTION.

APPENDIX A

SUMMARY OF FALLOUT DOCUMENTATION PROJECTS

PROJECT 2.1

Title: Gamma Exposure Versus Distance, ITR 1310.

PROJECT 2.2

Title: Gamma Exposure Rate Versus Time, ITR 1311.

Project Officer: Mr. Peter Brown.

Agency: Evans Signal Laboratory (ESL).

These projects placed film packs and dosimeters throughout Bikini Atoll and aboard a number of the floating stations. Some of the stations were also instrumented with an ion chamber and recording device to document the radiation exposure rate as a function of time. The initial radiation measurements also made by these projects have not been considered in this report.

PROJECT 2.61

Title: Rocket Determination of the Activity Distribution Within the Stabilized Cloud, ITR 1315.

Project Officer: Mr. Richard R. Soule.

Agency: U.S. Naval Radiological Defense Laboratory (NRDL).

Ion chamber detectors and telemeter transmitters were mounted in the heads of 6½ inch rocket propelled Atmospheric Sounding Projectiles (ASP). These rockets were then flown through the nuclear cloud (and stem) from shots CHEROKEE, ZUNI, NAVAJO, and TEWA and the telemetered exposure rate data was received and recorded at duplicate stations aboard the USS KNUDSON (APD 101) and NAN Island in Bikini Atoll.

PROJECT 2.62

Title: Fallout Contours by Oceanographic Analysis, ITR 1316.

Project Officer: Mr. Feenan D. Jennings.

Agency: Scripps Institution of Oceanography (SIO).

The lagoon and ocean fallout areas were surveyed using an LCU, two destroyer escorts, and the oceanographic survey vessel M/V HORIZON. The surveys included radiation intensity readings in the water near the surface and intensity versus depth profiles. The effect of water currents and the location of the thermocline was determined using data from a pre-CHEROKEE oceanographic survey. This project also was responsible for the mooring and servicing of the skiff array which was located in the deep ocean north of Bikini. The skiffs were instrumented for fallout collection, time of arrival, total exposure, and rate of penetration of the activity in the water measurements. Equipment for the measurement of depth of penetration of activity in ocean water was also placed aboard the YAG 39 and YAG 40.

PROJECT 2.63

Title: Characterization of Fallout, ITR 1317.

Project Officer: Dr. Terry Triffet.

Agency: U. S. Naval Radiological Defense Laboratory (NRDL).

This project provided the majority of collectors and detectors placed aboard the floating collection stations. Complete instrumentation, including incremental and total collectors, exposure rate recorders, and total exposure instruments, were placed aboard the two YAG's, an LST, two YFNB barges moored in Bikini Lagoon, and at the northern end of HOW Island in Bikini Atoll. In addition, the YAG-40 had a shielded laboratory in which radiation rate, microscopic, and spectrometric measurements could be performed on the fallout samples as they arrived. Total collectors, total exposure instruments, and time of arrival detectors were placed aboard the deep moored skiffs provided by Project 2.62, three pontoon rafts in Bikini Lagoon, and at Sites GEORGE, WILLIAM, and CHARLIE in Bikini Atoll.

PROJECT 2.64

Title: Fallout Location and Delineation By Aerial Survey, ITR 1218.

Project Officer: Mr. Robert T. Graveson

Agency: New York Operations Office, U. S. Atomic Energy Commission (NYOO/AEC)

P2V aircraft were instrumented to measure gamma exposure rate and were flown over the ocean fallout areas to perform as rapid and complete a survey as possible. Calibration flights with a spectrometer in a helicopter and radiochemical analysis of water samples were performed to reduce the data to absolute intensities. Instrumentation for cross correlation was placed on the YAG-39 and YAG-40.

PROJECT 2.65

Title: Land Fallout Studies, ITR 1219.

Project Officer: Mr. Manfred Morgenthau.

Agency: Chemical Warfare Laboratories, Army Chemical Center (CWL/ACC).

This project provided the primary land fallout collecting stations and instrumented a number of islands in Bikini Atoll with total and incremental collectors. A small number of stations were instrumented for one "small" shot at Eniwetok. One remote collector was located at Rongerik Atoll, 130 miles southeast of Bikini. The samples from these collectors were subjected to radiophysical and radiochemical analyses to determine specific activity, particle sizes, distribution of activity on and within the particles, chemical fractionation, etc. Some instrumentation was placed on a number of the floating stations for correlation purposes. This project also made gamma ~~dose~~ exposure rate measurements on islands in both the Bikini and Eniwetok Atolls by means of a detector which was lowered to the ground from a helicopter.

PROJECT 2.66

Title: Early Cloud Penetration, ITR 1320.

Project Officer: Colonel Ernest A. Pinson, USAF.

Agency: Air Force Special Weapons Center, Air Research and Development Command (SWC/ARDC).

B57-B aircraft, completely instrumented for exposure rate and total exposure were flown for brief periods within the nuclear clouds to obtain personnel exposure and aircraft contamination data.

PROJECT 2.71

Title: Ship Shielding Studies, ITR 1321.

Project Officer: Mr. Heinz Rimmert.

Agency: U. S. Naval Radiological Defense Laboratory (NRDL)

This project, while basically intended for ship shielding studies, provided gamma ~~dose~~ exposure rate information in conjunction with Project 2.63 on the ships in the region of fallout.

APPENDIX B

CONSTRUCTION OF PARTICLE FALL PLOTS

The construction of a particle fall plot begins with the assumption of a vertical line source of particles above ground zero. For the purposes of the Program 2 operational plots and those presented in this report constructions were made for four particle sizes only: 75, 100, 200, and 350 microns.

The wind velocity observed at a 5,000 feet interval was assumed to represent the average wind throughout the 5,000 feet layer centered at that height. Therefore the wind velocity, multiplied by the time a particular particle takes to fall through a 5,000 feet layer, gives the horizontal displacement of the particle. The particle fall times were calculated from aerodynamic equations, choosing a representative air density and viscosity profile for the Marshall Islands atmosphere.

In constructing a pattern which neglects space and time variation of the wind profile, the static hodograph is most convenient. It can be drawn simply by placing the displacement vectors end to end commencing with the lowest altitude. The resultant line represents the locus along which the given size particles from all altitudes arrive. The same procedure is repeated for each of the particle sizes. The locus of all particles from a given altitude can then be sketched through the individual points.

A time varying analysis necessitates more labor. Since the winds at a particular altitude change as particles from different altitudes above arrive, the simple hodograph cannot be used. The procedure of constructing the actual projected trajectories must be followed. This procedure involves constructing a complete trajectory for each particle size from each altitude.

The space variation can also be included in this analysis.

The particle fall plots in this report have been constructed including time and space variations whenever these had appreciable effects on the pattern.

For the purposes of fallout prediction, particularly as applied to the problem of positioning ships from the Program 2 Control Center (see Section 2.3.6), the predicted winds were necessarily utilized. Since the predicted time variation is even more uncertain than the predicted zero time wind profile, the former was not included in the initial analysis. Shot time and later wind observations were used in a time varying analysis to reposition fallout collecting ships until they received fallout and to direct the motion of survey vehicles so as to avoid receiving direct fallout.

The positions of the fallout collecting ships were determined by assuming that the majority of the activity was in the lower third of the initial cloud. The limit of interest is given by the 75 micron particles since these fall at late times over very large areas and have only a small fraction of the total activity associated with them. The times of arrival and cessation of fallout were calculated from the constructed pattern and the particle fall time data, assuming the effective radiological cloud to have the dimensions of the visible cloud except when considering the larger particles. One thousand micron diameter particles were assumed to be present in only the inner 10 percent and 500 micron particles in 50 percent of the cloud. This assumption modified the close-in fallout to correspond to actual observations at previous operations.

It was not necessary in any of this work to associate a specific activity concentration with each region of the cloud and particle size and hence to determine the actual radiation pattern. It is an aim of this report to present data out of which such associations can be made.

APPENDIX C

RADIATION CONVERSION FACTORS

For the purposes of the calculations in this report, certain conversion factors were needed to reduce radiation data to a common basis. The factors related to the conversion of gamma exposure rates between different distances from the source have been calculated in Reference 31 and are summarized in Table C1. The factors relating the observed exposure rates to the density of active sources have also been derived in Reference 31 and are summarized in Table C2.

TABLE C1 HEIGHT CONVERSION FACTORS FOR GAMMA EXPOSURE

	Height Above Surface in Feet						
	10	25	50	100	250	500	1000
Factor to convert reading above land to height of 3 ft	1.4	1.7	2.2	3.1	5.2	12	46
Factor to convert reading above water to height of 3 ft	1.0	1.1	1.1	1.2	1.5	2.2	6.2

Note: For RadSafe aerial readings an additional factor of 1.5 was found to be necessary to normalize readings to Project 2.65 helicopter probe readings.

TABLE C2 CONVERSION OF ACTIVITY DENSITY TO EXPOSURE RATE

Volume density of activity in water............	1 curie/m^3
Exposure rate reading in water...............	0.6 r/hr
Exposure rate reading 3 ft above water.......	0.3 r/hr
Volume density of activity in air at STP.......	1 curie/m^3
Exposure rate reading in air.................	1200 r/hr
Surface density of activity on land............	1 curie/m^2
Exposure rate at 3 ft above land..............	6 r/hr

[redacted]

APPENDIX D

INTERPRETATION OF EXPOSURE RATE VERSUS AREA PLOT

A plot of converted H+1 hour exposure rates versus area of contour on contour on log-log paper is a particularly useful tool for analyzing the fraction of the weapon's fission products which has been deposited in the local fallout pattern. It appears that such a plot can usually be fitted by a straight line of slope -1 over a portion of the data, with the extreme points falling below this line. In particular the predicted values from Reference 29 fall on such a line for more than a factor of 100 in area or exposure rate. This line on log-log paper represents a reciprocal relation between exposure rate and area. It has a particular significance in terms of the integral of the exposure rate over the area. For this reciprocal relationship the value contributed to the integral by any particular range of exposure rates is the same as that contributed by another range having the same ratio of upper to lower values. Therefore, most of the material deposited will be associated with the part of the curve that fits the line of slope -1, and a smaller portion with the points that fall below this line. A crude estimate of the radiological yield observed can thus be calculated by multiplying the area = 1 intercept by the natural logarithm of the ratio of the upper and lower area values for which the straight line makes a reasonable fit to the data. For example, in Figure 4.1 the extrapolated 5 MT predicted straight line section has an intercept of approximately 7.5 X 10^5 r/hr at an area of 1 square mile. The straight line fits the prediction over areas covering a factor of 500. Therefore, the integrated material corresponds to

$$7.5 \times 10^5 \log_e 500 = 4.7 \times 10^6 \text{ mi}^2 \text{ r/hr}.$$

Assuming a conversion factor of 1200 mi^2 r/hr per KT (very uncertain; assumes 300 megacuries at H+1 per KT), the material accounted for represents 3.9 MT or 78 percent of the total yield.

APPENDIX E

FRACTION OF SHOT ACTIVITY IN FALLOUT

For the purpose of checking a number of parameters, the quantity of radioactive material in the fallout areas were calculated and compared with the activity resulting from the fission yield of the bomb. The normalization factor used was 4000 mi^2 r/hr per KT of fission yield. This factor was derived by examining a draft of the Operation CASTLE Project 2.7 report (Reference 32).

The total activity encompassed by the CASTLE Shot 5 contours was normalized to 10% of the weapon's fission yield which was determined to be inside these contours by an absolute beta counting technique. The percent of the total activity for REDWING shots is presented in Table E1. The percentage of activity values as given, must be accepted with reservation since the errors and uncertainties in the decay exponents and normalization factors can easily amount to factors of 2.

[redacted]

TABLE F1

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* Based on 4000 mi^2 r/hr per KT.

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